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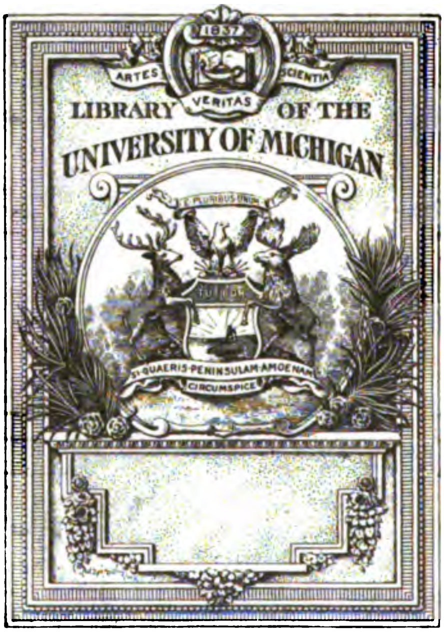

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U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF SOILS—BULLETIN No. 48.

MILTON WHITNEY, Chief.

FERTILITY OF SOILS AS AFFECTED BY MANURES.

BY

FRANK D. GARDNER.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1908.

(M)

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., June 24, 1907.

Sir: I have the honor to transmit a manuscript entitled Fertility of Soils as Affected by Manures, by Frank D. Gardner, in charge of Soil Management. It embodies the results of a uniform scheme of manurial treatments, as measured by the resulting increase in plant growth on soils collected from 220 fields in 23 States, located in the eastern half of the United States.

The increasing use of manures, and especially of commercial fertilizers, by the farmers of the United States is sufficient justification for careful investigations as to the relative efficiency of various forms of manures on different soils. You will find here a vast amount of data, treated in a manner commensurate with the importance of the subject. It should be of great value to all who are interested in the use of manures.

The manuscript has been gone over carefully with Assistant Secretary Hays, who concurs in my recommendation for its publication as Bulletin No. 48 of the Bureau of Soils.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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FERTILITY OF SOILS AS AFFECTED BY MANURES.[a]

INTRODUCTION.

The use of manures as a means of increasing the growth of crops dates back to ancient times. At the time of the discovery of America, the North American Indians used dead fish as a manure for corn. The Peruvians have used guano since the beginning of their recorded history, and the Chinese have long recognized the value of all kinds of excrements as fertilizers. In the early part of the last century De Saussure established the existence of the mineral constituents of the soil in plants, and while he believed that they were essential to the life of plants, his contemporaries regarded them as nonessential, or at the best useful only as a kind of stimulant.

Justus Von Liebig, as a result of his investigations, published in 1843 a new edition of his notable work, "Chemistry in its Application to Agriculture and Physiology," in which it may be said he laid the foundation of the celebrated "mineral theory" of agriculture.

Prior to the time of Liebig the use of manures and fertilizers was purely an art, the beneficial results of which had not been satisfactorily explained. Liebig's mineral plant food theory, apparently so ample, and in time widely accepted, attributed the beneficial effect of fertilizers solely to the plant food constituents which were supplied to the growing plants, and thereby laid the foundation for the compounding of fertilizers to meet the needs of soils and crops. There soon sprang into existence a soil chemistry which had for its object an investigation of the stores of plant food in soils with a view to ascertaining the agricultural value of lands, as well as the character and amount of fertilizer, if any, that would give the largest net crop income per acre. It was soon learned that the soil constituents existed in various forms or compounds not all of which were available as plant food, and this led to a study of inexpensive methods of determining the available constituents, a study which has formed no small part of soil chemistry even down to the present time, with little indication that a method will ever be devised that will prove universally satisfactory for all soils and crops.

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[a] A comparative study of the fertility of the soils of the central and eastern United States, as influenced by manures and fertilizers and measured by the paraffin-pot method.

So far as can be gleaned from the writings of soil investigators, only within recent years have any considerable number of them come to realize that there is no definite relation between the available plant food constituents of soils, as determined by mineral analysis, and their crop-yielding capacities. Neither had they arrived at that further realization that the crop-yielding capacity of a soil is dependent upon a complexity of factors, any one of which may be dominant, but all of which are concerned in large or small degree.

Arable soils contain the organic remains of previous crops together with excretions produced during their growth and are also filled with living forms. Their bacterial flora is diversified and the activities and processes which take place within the soil, physical, chemical, and biological, are exceedingly complex, and at present but imperfectly understood. It is the sum total of these activities and their products that determines largely the fitness of a soil for plants, rather than the variation in the character and composition of its mineral matter. While manure and fertilizers may often increase crop yields as a result of a direct supply of plant food or as a stimulant to the plants, there is now abundant evidence that their effect is rather the result of a direct action upon the soil, thereby changing its relation to plants. Complex and imperfectly understood as is this action, it is a more satisfactory explanation of the benefits derived from fertilizers than the idea that the inconsequential amounts of nitrogen, potash, and phosphorus applied, as compared with the larger stores of those elements already in the soil, should be directly responsible for such marked increase in growth as frequently follows the application of fertilizers.

The prime object of manuring the soil, whether with stable manure, green manure, or commercial fertilizers, is to increase its crop-yielding capacity, and in order to justify the practice the resulting increase in product must be more than enough to offset the cost of the fertilizers applied. That is to say, the beneficial effect on the present and succeeding crops must be sufficient to compensate for the cost of the fertilizers and give a profit on the capital so invested.

The first noteworthy use of commercial fertilizers in the United States was in 1848, during which year there was imported 1,000 tons of guano. This was followed the succeeding year by twenty times that quantity, after which date the importation steadily increased until 1880, when it reached its maximum and began to fall off because of a failing supply. Other materials, notably sodium nitrate from Chile and the potash salts from Germany, have taken the place of the failing supply of guano, and these, together with the development of our phosphate mines, the use of cotton-seed meal, and the utilization of slaughterhouse by-products, have met the continually increasing demand for commercial fertilizers by our farmers. According to our census reports, the expenditure for fertilizers in the United States in 1880 was $28,500,000. Ten years later it was $38,500,000, and in 1900 it reached the significant sum of $54,750,000. There seems little doubt that this rate of increase in the use of fertilizers will continue for some time to come, and the subject is one of sufficient national importance to justify careful investigations.

OBJECT OF THE INVESTIGATION.

The object of this investigation is not for the purpose of explaining how fertilizers act nor of studying the relation of the composition of the soil to the beneficial effect of the fertilizer when applied to it, but rather to compare the effects of several high-grade standard fertilizer ingredients, lime, stable manure, and cowpea vines when applied under like conditions to a large number of soils, collected from widely separated areas and representing a wide range in soil texture, type, origin, and crop adaptation. By making a comparative test of a large number of soils it was thought that there might be established a relation between the manurial requirements and the origin, formation, type, or crop adaptation of the soil.

While there has been recorded in agricultural literature, in the aggregate, a large number of field tests of fertilizers on a great variety of soils, representing nearly every State in the eastern half of the United States, it is impossible to make a satisfactory comparison of the results obtained, because of the innumerable details in which the conditions of the tests do not agree. The variation in the amount, class, kind, and composition of the fertilizer used, the time and manner of its application, the test crop used, and the weather conditions which prevailed form such a wide range of possible combinations that it is rare to find two tests that are strictly comparable.

In the present investigation the same variety of wheat was used throughout as the test crop, and all of the conditions for growth, excepting the manurial treatments to be tested, were maintained as nearly uniform as possible. With the same fertilizer ingredients, in like form and used in the same combinations, for a crop common to all, the results obtained from this large number of soils are strictly comparable, and far exceed in number any similar tests that can be brought together on such a basis.

Mention should also be made of the fact that all tests reported in the following tables under areal surveys—and they constitute fully four-fifths of them—were made for the further purpose of gaining practical knowledge concerning the manurial requirements of the principal soil types as established by the soil survey parties and with the ultimate object of determining what manures or fertilizers would give best results on the soils. The results of all such tests are reported in general terms in the soil survey reports for the respective areas in which they occur.

THE SOILS.

The soils tested in this investigation, 220 in number, represent 90 types, half that number of soil series, and many geological formations. The samples were taken from twenty-three States, extending from the Mississippi River to the Atlantic seaboard and from Rhode Island to Texas. With the exception of a limited number of miscellaneous samples, the greater number were collected from areas that were in process of being surveyed by the Bureau of Soils during the summer of 1905, and the following winter, and are representative of the soils of those areas rather than the vast expanse of country included in the twenty-three States above mentioned. Each sample, being a composite, made up of fifteen or twenty small samples, taken from different parts of the same field, is representative of the field from which it is taken as well as the type which it represents. The samples were placed in strong grain bags and shipped to the Bureau's headquarters, where they were at once transferred to covered galvanized iron cans for storage. In this way the original condition and original moisture content were, as far as practicable, maintained until they could be tested. This is important in relation to the test, for it has been found by experience that as a result of long storage and resulting air-dry condition soils become more productive and are usually less responsive to fertilizers than when such a change is prevented.

THE METHOD.

The paraffin-pot method, described in Circular No. 18 of this Bureau and in the appendix to Farmers' Bulletin No. 257 of the United States Department of Agriculture, was employed in these tests, and while it is not designed to supersede field tests, results obtained with it, when compared with results obtained on the same soils at the agricultural experiment stations in Rhode Island,[a] New York, Ohio,[b] Iowa, Missouri, and North Carolina, show that it will indicate the manurial requirements of soils for general farm crops with a fair degree of accuracy. It is also admirably adapted to an investigation of the character described in the following pages.

The soil to be tested is thoroughly pulverized by crushing all lumps, and if containing stone or gravel this is removed by sifting. The sample is then thoroughly mixed and equal amounts weighed into granite-ware pans, where they receive their respective applications of manure or fertilizers and are made up to their optimum water content with distilled water. After remaining in the pans for about a week, being occasionally wet with distilled water, and frequently stirred in order to secure a thorough incorporation of the fertilizer and a good soil condition, it is ready to pot and plant. Five small wire-gauze pots are used for each treatment. About 350 grams of soil is then placed in each pot, uniformly packed, and planted with six selected germinated kernels of wheat, after which the pots are dipped in melted paraffin, which not only forms an intimate contact with the soil but makes the pot water tight. The soil is then covered with a thin layer of washed quartz sand and the pot and contents weighed and weight recorded. The pots are next placed in trays and given a favorable exposure in the greenhouse for three or four days or until the plants attain a height of about 1½ inches, at which time the pots are sealed. The sealing consists of covering the tops with paraffined paper disks in which are slits through which the plants grow. The disks are sealed to the sides of the pots by means of melted paraffin. The loss of water by direct evaporation from the soil is in this way reduced to a negligible quantity.

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[a] See Bul. 109 of the Rhode Island Expt. Sta.

[b] See Buls. Nos. 167 and 168 of the Ohio Agricultural Expt. Sta.

During the growing of the plants, which usually continues from eighteen to twenty-one days from the date of sealing, the pots are weighed at intervals of two or three days and watered with distilled water in order to retain a favorable moisture content for plant growth. By this method the loss of water or the amount transpired by the plants may be ascertained periodically, and at the end of the experiment the total amount of water given off through the plants of each pot obtained for comparison with the growth and green weight of the plants, which is ascertained by cutting and weighing the plants at the time the experiment is concluded. All conditions of the experiment are so carefully controlled that the average result of five pots rarely differs more than 5 per cent from the average result of any other five pots that have been treated throughout in precisely the same manner (see Table I). Differences which occur beyond this amount may therefore safely be attributed to the different manurial treatments which have been given. This method has several advantages over the growing of plants in open and porous pots. The method of coating the soil with paraffin prevents any accumulation of roots between the soil and the receptacle, a trouble which is common in pot experiments. The complete sealing up of the soil also enables the experimenter to determine the amount of water which the plant has actually used and transpired in its process of growth, and this, together with the small size of the pots, enables the moisture content and its fluctuations to be carefully controlled.

On good soils, or as a result of favorable treatment, plants are produced in the little pots in twenty-five days or less time, the green weight of which sometimes equals or exceeds 1 per cent of the weight of the soil in which they grew. Such plants are approximately 85 per cent water; they have transpired about 100 units of water for each unit of green matter produced, and their dry matter is relatively richer in mineral constituents and nitrogen than that of mature plants. On this basis, an acre foot of soil, weighing 3,500,000 pounds, would produce 35,000 pounds of green matter, requiring for its production the equivalent of 17½ inches of rainfall. This green matter would be equivalent to 5,900 pounds of air-dry material, or about 50 bushels of wheat and 1½ tons of straw to an acre. While the removal of green matter equal to 1 per cent of the soil in the little pots is somewhat above the average, it serves as an illustration of the heavy draft made upon the soil in a very short time, a draft, as regards moisture and mineral constituents, although part of the latter comes from the seed, greater than that which takes place under field conditions by the removal of a large mature crop, assuming that the removal takes place to a depth not greater than 1 foot, which for wheat and similar crops would be approximately correct, and providing also the movement of plant food by capillarity from below 1 foot be ignored.

TABLE I.—*Actual transpiration in grams for each of twenty pots, on three soils, under uniform treatment, and the percentage variation from the average for each pot, also average percentage variation of each group of five pots.*

Leonardtown loam. Corn.			Cecil clay—poor.			Leonardtown loam.		
Transpiration.	Variation.		Transpiration.	Variation.		Transpiration.	Variation.	
For each pot.	For each pot.	For 5 pots.	For each pot.	For each pot.	For 5 pots.	For each pot.	For each pot.	For 5 pots.
Grams.	*Per cent.*	*Per cent.*	*Grams.*	*Per cent.*	*Per cent.*	*Grams.*	*Per cent.*	*Per cent.*
69.9	− 5.5	−0.9	39.3	+10.1	−2.8	87.5	+ 0.4	+3.3
77.6	+ 4.9		25.7	−28.0		90.5	+ 3.9	
58.7	−20.1		37.7	+ 5.6		89.1	+ 2.2	
83.5	+12.8		34.8	− 2.5		98.4	+12.9	
76.5	+ 3.3		35.9	+ 0.6		84.8	− 2.6	
59.1	−20.2	−3.0	35.8	+ 0.3	+4.1	89.9	+ 3.2	+1.6
72.1	− 2.6		37.3	+ 4.4		99.2	+13.9	
79.2	+ 7.0		38.6	+ 8.1		87.7	+ 0.7	
73.9	− 0.2		35.4	− 0.8		80.5	− 7.6	
74.1	+ 0.8		38.9	+ 8.9		85.2	− 2.2	
82.3	+11.1	+2.2	38.8	+ 8.6	+0.8	79.8	− 8.4	−2.7
66.8	− 9.8		33.6	− 5.9		79.5	− 8.7	
70.6	− 4.6		37.8	+ 5.9		86.1	− 1.1	
68.9	− 6.9		38.1	+ 6.7		88.8	+ 1.9	
89.9	+21.4		31.7	−11.2		89.5	+ 2.7	
84.3	+13.8	+2.0	34.7	− 2.8	−2.5	82.4	− 5.4	−2.1
79.0	+ 6.7		32.3	− 9.5		83.0	− 4.7	
76.4	+ 3.2		39.8	+11.2		94.3	+ 8.2	
68.3	− 7.7		36.9	+ 3.4		87.4	+ 0.3	
69.7	− 5.8		31.2	−12.6		79.3	− 8.9	

FERTILIZERS USED.

In this investigation the tests were confined to the use of high-grade, standard fertilizing materials, consisting of nitrate of soda, sulphate of potash, and acid phosphate, together with air-slaked lime, well-decomposed stable manure, and green cowpea vines. These ingredients were applied to the soil separately and in various combinations as follows:

Treatment and rate per acre.

1. Untreated.
2. Manure, 10 tons.
3. Lime, 1 ton.
4. Nitrate of soda, 200 pounds.
5. Sulphate of potash, 200 pounds.
6. Acid phosphate, 200 pounds.
7. Nitrate of soda and sulphate of potash, 200 pounds each.
8. Nitrate of soda and acid phosphate, 200 pounds each.
9. Sulphate of potash and acid phosphate, 200 pounds each.
10. Nitrate of soda, sulphate of potash, and acid phosphate, 200 pounds each.
11. Same, plus lime, 2,000 pounds.
12. Cowpea vines 5 tons, lime 2,000 pounds.

The rate of application is based on the weight of an acre of soil to the depth of 7 inches, which is approximately 2,000,000 pounds. The fertilizers were applied in solution, and the lime, manure, and cowpea vines in bulk, each being finely ground.

CALCULATION OF RESULTS.

While this report combines the results of more than 13,000 pots, individual record of which has been made, the results were reported on forms, of which the following is a sample:

[Can 101.]

Actual transpiration and green weight and relative transpiration and green weight of 30 wheat plants on the basis of 100 for the untreated soil.

Soil: Norfolk Sandy Loam. Locality: Waycross, Ga.
Planted: April 5. Sealed April 10. Disctd.: April 28. Basket Nos.: 2066-2125.

Number.	Treatment and parts per million.[a]	Transpiration, 18 days.	Green weight.	Relative variation by—	
				Transpiration.	Green weight.
1	Untreated	757.6	7.0	100	100
2	Manure 10,000	1295.2	14.2	171	203
12	Cowpeas 5,000, lime 1,000	1135.7	13.6	150	194
10	Nitrate of soda, potassium sulphate, and acid phosphate 100 each	1160.3	11.5	153	164
11	Same + lime 1,000	1090.1	11.0	144	157
7	Nitrate of soda and potassium sulphate 100 each	1047.2	10.8	139	154
8	Nitrate of soda and acid phosphate 100 each	997.6	9.6	132	137
4	Nitrate of soda 100	1053.0	9.5	139	136
5	Potassium sulphate 100	925.9	8.0	122	114
9	Potassium sulphate and acid phosphate 100 each	833.6	8.0	110	114
3	Lime 1,000	803.0	7.0	106	100
6	Acid phosphate 100	651.9	6.5	86	93

[a] Parts per million multiplied by 2 equals the pound rate per acre on the basis of 2,000,000 pounds as the weight of an acre of soil 7 inches deep.

On this form are given the total transpiration and total weight of green plants for each treatment, consisting of five pots. The transpiration and the green weight of plants for each treatment are entered in the third and fourth columns, respectively, while the relative transpiration and weight, based on 100 for the untreated soil, are given in the fifth and sixth columns and are merely computed from the actual transpiration and weight in order to convert the comparison to a percentage basis and make it more simple.

The variation by transpiration, while a good indication of the relative growth and effect of the treatments, frequently gives a range of lesser magnitude than the actual growth of plants. Plants that have made a marked increase in growth as a result of soil treatment usually contain a higher percentage of water than untreated ones and therefore show a slightly lesser variation by dry, or water-free, weight than by green weight. See Table II, which follows. The increase in growth is also accompanied by an improvement in condition which can only be measured by appearance, but which will usually prove an advantage to the better plants if grown to maturity. The results given in this bulletin are all based on the actual green weight of plants, the weighings being made immediately upon cutting the plants and under uniform conditions.

TABLE II.—*Percentage gain or loss attributable to various fertilizer treatments on four soils.*

[P=acid phosphate. K=sulphate of potash. N=nitrate of soda. L=lime. M=stable manure.]

A.—BASED ON GREEN WEIGHT OF PLANTS GROWN ON UNTREATED SOILS.

Soil.	Green weight of plants grown on untreated soils.	Percentage gain or loss attributable to—									
		P.	K.	N.	PK.	PN.	KN.	PKN.	L.	PKNL.	M.
	Grams.										
Cecil clay, good	8.8	0	– 2	– 4	......	9	14	– 4	5	....	9
Cecil clay, poor	8.8	– 1	1	0	......	– 6	7	5	6	....	–14
Leonardtown loam, good	8.3	16	7	47	......	41	47	46	10	....	17
Leonardtown loam, poor	6.5	– 7	15	8	......	0	12	22	1	....	24
Average	7.6	2	5	13	......	11	20	17	5	....	9

B.—BASED ON DRY WEIGHT OF PLANTS GROWN ON UNTREATED SOILS.

Soil.	Dry weight of plants grown on untreated soils.	Percentage gain or loss attributable to—									
		P.	K.	N.	PK.	PN.	KN.	PKN.	L.	PKNL.	M.
	Grams.										
Cecil clay, good	1.60	– 1	–11	– 9	......	– 1	3	13	–5	....	–11
Cecil clay, poor	1.55	– 3	– 4	0	......	– 8	8	5	–1	....	–17
Leonardtown loam, good	1.20	13	4	37	......	25	47	36	8	....	18
Leonardtown loam, poor	1.22	2	18	5	......	0	9	24	6	....	9
Average	1.39	3	2	8	......	4	17	19	2	....	0

ARRANGEMENT AND TABULATION OF RESULTS.

Table III, which follows, gives the actual green weight of plants grown on the untreated soils and the percentage increase or decrease in growth, the latter indicated by the minus (−) sign, resulting from the various fertilizer ingredients and combinations. The data are arranged by States, areas, and types and averages are given for areas and for types within areas. The symbols at the head of the columns are used for the sake of brevity. **P** stands for acid phosphate; **K** for sulphate of potash; **N** for nitrate of soda; **L** for air-slaked lime; **M** for well-rotted stable manure, and **Cv** for green cowpea vines. The ingredients and rate of application are given in the preceding form. All data resulting from the tests are embodied in Table III. Marked variations from the general trend are exceptional and most frequently occur with manure or cowpea vines. These substances have occasionally given negative results apparently as a result of decomposition products from which the soil did not have sufficient time to recover prior to the planting of the seed. The blanks in the table indicate no tests for the ingredients or combinations heading the columns in which they occur. Practically all such omissions occurred in miscellaneous samples which were tested by the Bureau parties at several of the State experiment stations. Table III gives the results for 220 soils and from these results many tabulations were made, parts of which are given on subsequent pages. The arrangement and segregation of data in subsequent tables are for the purpose of a further comparative study of the facts as well as to enable the reader to verify statements that may follow in the text, although a number of facts are given from tabulations other than those which follow.

TABLE III.—*Percentage increase in growth attributable to the various fertilizer applications.*

Soil type and locality.	Weight of plants grown on untreated soil.	Gain or loss attributable to—										
		P.	K.	N.	PK.	PN.	KN.	PKN.	L.	PKNL.	M.	CvL.
WISCONSIN.												
Portage County:	*Grams.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Miami stony sand	9.9	6	13	11	− 3	11	21	22	− 3	19	47	8
Miami sand	6.0	7	15	33	5	24	29	39	7	43	80	− 4
Miami sandy loam	9.0	4	8	2	− 1	10	14	3	4	21	29	12
Marshall gravelly loam	11.0	− 1	− 2	14	2	3	16	4	2	3	36	14
Marshall sand	8.4	7	9	31	13	23	32	35	11	8	34	3
Portage silt loam	10.0	−11	− 9	− 6	− 1	−10	− 3	3	5	10	21	10
Portage silt loam	8.7	2	−16	− 2	5	− 9	10	1	9	−14	42	−14
Average for area	9.0	2	3	12	3	7	17	15	5	13	41	4
MISSOURI.												
Crawford County:												
Clarksville silt loam	6.6	26	15	17	27	25	15	7	14	1	43	32
Wabash silt loam	7.6	−11	1	− 3	− 2	3	− 5	− 1	0	2	23	24
Clarksville stony loam	14.6	4	3	− 2	− 9	2	11	3	− 3	− 2	−10	13
Average for area	9.6	6	6	4	5	10	7	3	4	0	19	23

Table III.—*Percentage increase in growth attributable to the various fertilizer applications*—Continued.

Soil type and locality.	Weight of plants grown on untreated soil.	Gain or loss attributable to—										
		P.	K.	N.	PK.	PN.	KN.	PKN.	L.	PKNL.	M.	CvL.
MISSOURI—continued.												
Scotland County:	*Grams.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Shelby silt loam	9.6	7	24	14	22	17	32	28	11	28	69	30
Miscellaneous:												
Loess, McBain County	7.8	8	22	28	26	26	47	50	19	....	23	35
Clay loam, Salem	7.0	......	......	......	25	50	60	68	25	50	57	35
Silt loam, Columbia	5.9	......	......	......	29	54	44	61	7	66	34	50
INDIANA.												
Newton County:												
Marshall fine sandy loam	6.3	5	12	9	0	5	12	− 4	−12	− 1	60	− 2
Marshall loam	7.6	17	22	17	20	14	21	16	22	21	77	34
Clyde fine sand	12.6	−21	− 2	−14	− 8	−23	13	−17	−12	− 7	32	− 4
Average for area	8.8	0	11	4	4	− 1	15	− 2	− 1	4	56	9
Tippecanoe County:												
Marshall silt loam	7.2	4	1	6	10	......	3	12	− 7	6	− 2	4
Marshall loam	7.5	− 3	2	7	− 6	4	18	6	− 3	7	42	− 2
Miami silt loam	5.6	30	21	28	26	58	46	58	17	35	71	30
Average for area	6.8	10	8	14	10	31	22	25	2	16	37	11
OHIO.												
Westerville area:												
Miami black clay loam	8.3	−11	6	− 2	9	13	7	8	1	11	22	5
Miami clay loam	6.1	11	5	15	3	27	11	13	7	11	15	45
Miami loam	8.6	− 8	3	− 2	− 3	1	8	− 5	2	2	48	15
Average for area	7.8	− 3	5	4	3	14	9	5	3	8	28	22
Miscellaneous:												
Volusia silt loam, Wooster	5.8	0	......	......	14	47	46	62	21	76	52	......
Miami clay loam, Germantown	7.1	4	......	......	6	24	30	27	9	47	10	22
Miami clay loam, Strongsville	....	− 4	− 5	12	− 9	− 6	− 6	− 6	30	....	9	......
NEW YORK.												
Tompkins County:												
Dunkirk clay loam	9.0	0	9	13	− 1	6	23	11	−14	12	68	− 5
Dunkirk clay loam	4.5	−18	4	55	− 5	27	47	42	29	....	33	54
Average for type	6.8	− 9	7	34	− 3	17	35	27	8	....	51	25
Dunkirk loam	8.4	− 4	2	15	− 1	16	20	12	− 7	11	46	0
Miami stony loam	9.6	4	1	1	− 4	− 8	6	11	0	7	36	26
Average for area	7.9	− 5	4	21	− 3	10	24	19	2	10	46	19
Binghamton area:												
Dunkirk gravelly sandy loam	6.6	4	1	11	4	20	16	1	26	27	29	69
Dunkirk gravelly loam	10.6	9	9	1	− 8	0	9	7	− 3	−11	20	− 9
Wabash loam	10.6	− 1	11	5	16	12	22	26	10	15	31	10
Average for area	9.3	4	7	6	4	11	16	11	11	10	27	23
Other localities in State:												
Volusia silt loam	5.4	2	15	13	11	8	38	20	9	32	51	29
Volusia silt loam	4.8	− 2	15	34	15	21	53	35	15	62	81	......
Volusia silt loam	6.6	4	22	10	11	4	19	23	8	15	77	13
Dunkirk clay loam	8.9	16	29	20	31	10	21	28	19	22	17	28
Dunkirk clay loam	10.2	11	11	18	− 5	− 6	6	5	8	0	17	21

TABLE III.—*Percentage increase in growth attributable to the various fertilizer applications*—Continued.

Soil type and locality.	Weight of plants grown on untreated soil.	Gain or loss attributable to—										
		P.	K.	N.	PK.	PN.	KN.	PKN.	L.	PKNL.	M.	CvL.
PENNSYLVANIA.												
Montgomery County:	*Grams.*	*P. ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P. ct.*	*P.ct.*	*P. ct.*	*P.ct.*	*P. ct.*
Hagerstown loam.....	10.3	13	− 2	1	11	13	6	9	6	23	20	29
Penn silt loam.........	12.3	8	12	8	11	11	24	13	− 8	4	24	36
Lansdale silt loam....	9.9	0	23	1	27	− 7	31	7	19	17	9	30
Chester loam..........	7.8	0	9	4	21	18	15	27	4	33	13	8
Average for area....	10.1	5	10	4	18	9	19	14	5	19	17	24
RHODE ISLAND.												
The State:												
Miami silt loam, Kingston.................	3.6	− 8	−19	−14	28	22	22	31	133	111	39	.....
Miami stony loam, Middleton............	7.8	.....	.....	.....	.....	.....	.....	18	9	41	.....	.....
Miami stony loam, Jamestown..........	5.8	.....	.....	.....	.....	.....	.....	24	60	94	.....	.....
Miami stony loam, Curtis Corners.......	6.7	.....	.....	.....	.....	.....	.....	7	5	43	.....	.....
Miami stony loam, Woonsocket.........	9.1	.....	.....	.....	.....	.....	.....	10	10	17	.....	.....
Miami stony loam, Little Compton.....	15.4	.....	.....	.....	.....	.....	.....	5	0	8	.....	.....
Miami stony loam, Ashaway............	5.6	.....	.....	.....	.....	.....	.....	4	21	35	.....	.....
Average for type....	8.4	.....	.....	.....	.....	.....	.....	11	18	40	.....	.....
Gloucester stony loam, East Greenwich.....	8.7	.....	.....	.....	.....	.....	.....	15	2	37	.....	.....
Gloucester stony loam, Chepachet...........	8.5	.....	.....	.....	.....	.....	.....	4	9	21	.....	.....
Gloucester stony loam, Tarkiln..............	11.4	.....	.....	.....	.....	.....	.....	3	0	0	.....	.....
Gloucester stony loam, Foster...............	8.5	.....	.....	.....	.....	.....	.....	2	25	14	.....	.....
Gloucester stony loam, Greene..............	7.2	.....	.....	.....	.....	.....	.....	−22	8	30	.....	.....
Average for type..	8.9	.....	.....	.....	.....	.....	.....	0	9	20	.....	.....
Alton stony loam, Hope Valley.........	5.5	.....	.....	.....	.....	.....	.....	34	38	54	.....	.....
Alton stony loam, Wickford............	4.7	.....	.....	.....	.....	.....	.....	51	− 2	51	.....	.....
Average for type..	5.1	.....	.....	.....	.....	.....	.....	43	18	53	.....	.....
Warwick sandy loam, Alton................	7.1	.....	.....	.....	.....	.....	.....	41	− 8	42	.....	.....
Warwick sandy loam, Barrington..........	7.2	.....	.....	.....	.....	.....	.....	23	28	42	.....	.....
Average for type..	7.2	.....	.....	.....	.....	.....	.....	32	10	42	.....	.....
Average for area ..	7.9	.....	.....	.....	.....	.....	.....	15	14	35	.....	.....
VIRGINIA.												
Louisa County:												
Cecil sandy loam......	7.2	24	5	13	31	13	27	30	5	39	25	57
Cecil loam.............	4.6	36	47	75	26	75	100	102	71	153	63	158
Average for area....	5.9	30	26	44	28	44	64	66	38	96	44	108
Hanover County:												
Wickham sandy loam.	7.5	− 3	5	11	−1	10	16	36	9	35	31	−12
Norfolk sandy loam...	7.5	3	11	20	16	17	35	30	− 1	47	44	− 8
Average for area	7.5	0	8	16	8	14	26	33	4	41	38	10

Table III.—*Percentage increase in growth attributable to the various fertilizer applications*—Continued.

Soil type and locality.	Weight of plants grown on untreated soil.	Gain or loss attributable to—										
		P.	K.	N.	PK.	PN.	KN.	PKN.	L.	PKNL.	M.	CvL.
VIRGINIA—continued.												
Appomattox County:	*Grams.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Cecil clay	12.9	.....	.....	6	−13	4	12	2	− 1	2	− 3	24
Cecil clay, Pocahontas field	11.7	− 3	4	− 3	− 2	.....	.....	9	− 6	7	− 2	7
Cecil clay, Mitchell field	13.2	− 7	.....	4	3	.....	.....	6	5	− 4	2	6
NORTH CAROLINA.												
New Hanover County:												
Norfolk sand	4.1	37	41	122	61	124	131	151	66	154	241	144
Norfolk fine sand	6.4	3	9	37	20	45	51	63	16	70	94	37
Norfolk fine sandy loam	7.3	3	3	22	3	20	33	29	8	31	57	34
Portsmouth fine sand	3.0	13	30	77	40	87	117	110	70	173	180	230
Average for area	5.2	14	21	65	31	60	83	88	40	107	131	111
Miscellaneous:												
Cecil clay (good), Statesville	8.8	0	− 2	− 4	.....	9	14	− 4	5	....	9	.....
Cecil clay (poor), Statesville	8.8	− 1	1	0	.....	− 6	7	5	6	....	−14	3
Cecil clay, Iredell test farm	4.5	86	34	42	90	97	35	105	45	105	90	.....
Cecil sandy loam, Raleigh	4.1	20	31	30	29	23	39	49	52	103	53	54
Iredell clay loam, Statesville	5.2	7	21	16	19	9	28	34	− 1	28	33	.....
Norfolk fine sandy loam, Edgecombe	4.8	44	42	63	33	52	71	56	25	77	66	.....
Norfolk fine sandy loam, Tarboro	3.0	25	22	42	29	51	59	63	1	70	38	78
Porters clay, Asheville	5.8	− 6	− 2	29	−14	24	40	19	10	53	8	15
Porters clay, Biltmore	12.4	11	15	18	16	26	11	25	31	26	61	24
Porters sandy loam, Blantyre	4.5	4	44	20	31	20	51	24	43	22	61	31
Portsmouth sand, Pinehurst	4.8	42	26	42	35	43	38	56	26	46	41	45
Portsmouth silt loam, Chowan County	4.5	2	19	14	16	23	62	62	19	57	46	74
Silt loam, Union County	4.6	− 4	0	32	19	19	21	42	4	51	28	.....
Tobacco soil, Wake County	4.7	9	11	28	20	17	22	30	11	16	.....	.....
SOUTH CAROLINA.												
York County:												
Cecil sand	3.9	−15	− 8	26	28	8	20	54	8	71	90	60
Cecil sandy loam	7.0	40	3	28	− 9	0	40	34	33	41	76	58
Iredell clay loam	7.7	0	6	19	1	6	16	18	3	17	51	19
Average for area	6.2	8	0	24	7	5	25	35	15	43	72	46
Cherokee County:												
Cecil clay	7.4	− 4	− 6	36	− 2	26	39	35	4	44	42	12
Cecil silt loam	6.6	2	1	52	9	47	52	48	39	56	81	74
Cecil fine sandy loam	5.9	− 3	7	46	− 1	46	46	52	29	68	88	123
Cecil sandy loam	6.9	−12	28	35	9	33	60	58	4	65	71	5
Iredell clay loam	9.1	− 3	7	32	1	27	46	27	14	42	36	7
Average for area	7.2	− 4	7	40	3	36	49	44	18	55	64	44
Lancaster County:												
Cecil silt loam	7.3	.....	.....	75	15	63	61	67	8	73	10	111
Miscellaneous:												
Orangeburg sandy loam, St. Matthews	11.8	0	− 2	15	5	16	14	26	19	28	25	17
Portsmouth sandy loam, Darlington	5.3	.....	.....	13	9	35	26	30	40	105	44	138

TABLE III.—*Percentage increase in growth attributable to the various fertilizer applications*—Continued.

Soil type and locality.	Weight of plants grown on untreated soil.	Gain or loss attributable to—										
		P.	K.	N.	PK.	PN.	KN.	PKN.	L.	PKNL.	M.	CvL.
TENNESSEE.												
Henderson County:	*Grams.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Lexington silt loam....	7.5	1	1	36	5	16	44	36	5	57	72	17
KENTUCKY.												
McCracken County:												
Memphis silt loam.....	5.0	−3	3	39	8	25	42	42	18	48	70	−2
GEORGIA.												
Waycross area:												
Norfolk sand, 12 miles west Waycross......	5.5	−9	24	45	27	49	65	72	64	109	124	118
Norfolk sand, 4½ miles SE. Waycross.......	5.6	−4	30	61	18	45	50	57	20	121	114	132
Norfolk sand, 3½ miles NW. Waltertown ...	6.1	−2	−5	36	5	22	41	24	34	55	77	65
Average for type....	5.7	−5	16	47	17	39	52	51	39	95	105	105
Norfolk fine sand, 3 miles W. Waycross..	6.1	7	15	55	23	49	69	74	34	84	102	107
Norfolk fine sand, 8 miles SE. Waycross.	6.0	5	8	53	−2	18	38	50	27	32	113	107
Norfolk fine sand, 2 miles W. Waycross..	7.4	−9	−8	−3	−6	−12	0	14	6	25	28	36
Average for type..	6.5	1	5	35	5	18	36	46	22	47	81	83
Norfolk Sandy loam, 2½ miles N. Waycross................	7.0	−7	14	36	14	37	54	64	0	57	103	94
Norfolk sandy loam, 3 miles NW. Waycross................	6.5	11	15	54	15	77	102	85	35	100	109	109
Norfolk sandy loam, 2½ miles SW. Elsie....	5.0	0	16	20	3	15	42	25	−9	43	54	42
Average for type..	6.2	1	15	37	11	43	66	58	9	67	89	82
Norfolk fine sandy loam, 5½ miles W. Waycross...........	7.5	17	28	60	23	63	83	73	40	89	113	113
Norfolk fine sandy loam, 3 miles E. Waycross...........	7.9	1	5	29	6	21	38	24	22	35	96	67
Norfolk fine sandy loam, 4 miles N. Manor...............	3.9	11	29	74	35	51	79	86	64	105	150	176
Average for type..	6.4	10	21	54	21	45	67	61	42	76	120	119
Portsmouth fine sand. 5½ miles SE. Waycross................	5.2	6	21	73	31	92	104	77	29	117	150	148
Portsmouth fine sand, 1 mile S. Needham....	5.2	1	15	50	26	75	80	90	92	153	219	175
Portsmouth fine sand, 1 mile S. Glenmore...	5.5	2	18	33	24	33	29	71	20	75	64	109
Average for type..	5.3	3	18	52	27	67	71	79	47	115	144	144
Average for area...	6.0	2	15	45	16	42	59	59	32	80	108	107
FLORIDA.												
Escambia County:												
Portsmouth sand......	8.3	2	5	12	5	18	11	11	48	48	47	35
Norfolk sand..........	5.4	16	18	13	11	11	13	11	46	74	83	107
Norfolk sand..........	5.9	5	32	45	15	20	84	46	24	55	94	97
Norfolk sand..........	7.2	4	19	33	9	16	41	22	29	23	66	65
Average for type...	6.2	8	23	30	12	16	46	26	33	51	81	90

TABLE III.—*Percentage increase in growth attributable in the various fertilizer applications*—Continued.

Soil type and locality.	Weight of plants grown on untreated soil.	Gain or loss attributable to—										
		P.	K.	N.	PK.	PN.	KN.	PKN.	L.	PKNL.	M.	CvL.
ARKANSAS—continued.												
Prairie County—Cont'd.	*Grams.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Morse clay	8.8	− 9	8	1	2	11	6	0	6	− 7	6	22
Morse clay	10.8	4	− 3	2	− 7	2	6	− 3	2	4	4	9
Morse clay	11.1	5	13	− 3	4	3	9	−11	− 7	− 1	5	4
Average for type	10.2	0	6	0	0	5	7	− 5	0	− 1	5	12
Acadia silt loam	11.2	0	4	29	11	25	24	27	12	33	46	27
Acadia silt loam	7.3	1	7	10	12	1	10	15	14	37	7	16
Acadia silt loam	7.4	22	20	29	31	18	22	41	23	48	31	38
Acadia silt loam	9.0	0	11	6	11	31	26	18	−11	41	32	21
Average for type	8.7	6	11	19	16	19	21	25	10	40	29	26
Waverly silt loam	6.5	15	20	27	27	15	31	38	61	55	38	54
Waverly silt loam	7.8	− 7	9	− 7	− 3	− 4	4	− 3	37	40	18	41
Waverly silt loam	5.0	28	20	18	23	22	29	28	104	150	10	132
Average for type	6.4	12	16	13	16	11	21	21	67	82	22	76
Average for area	8.3	5	10	12	8	11	15	14	26	40	21	36
TEXAS.												
San Marcos area:												
Blanco loam	8.7	17	21	19	21	23	10	33	20	21	28	37
Crawford silt clay	9.2	20	21	31	20	40	29	22	20	42	40	52
Crawford silt clay	9.2	− 7	2	19	− 1	8	19	23	4	31	14	34
Crawford silt clay	8.8	13	25	30	18	29	30	42	24	46	56	11
Average for type	9.1	9	16	27	12	26	26	29	16	40	37	32
Houston black clay	7.9	8	8	21	8	23	9	30	15	21	30	42
Houston black clay	8.9	0	4	15	17	4	9	17	5	23	8	23
Houston black clay	7.0	20	21	31	25	33	35	35	17	42	10	38
Houston black clay	8.1	− 4	− 5	21	5	12	21	19	6	26	25	32
Average for type	8.0	6	7	22	14	18	19	25	11	28	18	34
Average for area	8.5	8	12	23	14	22	20	28	14	32	26	34
Rusk County:												
Caddo fine sandy loam	8.2	6	2	53	5	51	53	47	7	47	61	57
Caddo fine sandy loam	8.1	12	11	40	15	43	35	34	17	36	62	40
Average for type	8.2	9	7	47	10	47	44	40	12	42	62	49
Norfolk fine sand	8.5	14	16	41	16	29	54	49	21	55	86	48
Norfolk fine sand	7.8	− 4	8	21	6	17	28	28	3	60	103	69
Norfolk fine sand	8.6	5	6	19	− 3	21	36	36	10	26	61	37
Average for type	8.3	5	10	27	6	22	39	38	11	47	83	51
Norfolk fine sandy loam	7.5	20	28	38	41	42	62	65	21	64	105	62
Norfolk fine sandy loam	6.1	31	31	48	48	52	56	48	40	41	48	80
Average for type	6.8	26	30	43	45	47	59	57	31	53	76	71
Orangeburg fine sandy loam	9.2	−12	− 6	14	− 9	− 6	14	36	13	39	68	53
Orangeburg fine sandy loam	9.2	0	2	34	− 1	26	26	26	12	37	37	66
Orangeburg fine sand	7.5	− 7	20	31	24	27	39	40	8	60	80	68
Susquehanna fine sandy loam	7.0	− 3	0	9	− 3	3	3	9	−11	26	29	36
Average for area	8.0	6	11	32	13	28	37	38	13	45	67	54

TABLE III.—*Percentage increase in growth attributable to the various fertilizer applications*—Continued.

Soil type and locality.	Weight of plants grown on untreated soil.	Gain or loss attributable to—										
		P.	K.	N.	PK.	PN.	KN.	PKN.	L.	PKNL.	M.	CVL.
TEXAS—continued.												
Miscellaneous:												
Galveston clay, Galveston	*Grams.* 11.2	*P. ct.* −14	*P. ct.* −12	*P. ct.* 3	*P. ct.* −23	*P. ct.* − 9	*P. ct.* 4	*P. ct.* −20	*P. ct.* − 2	*P. ct.* − 8	*P. ct.* 4	*P. ct.* 31
Houston black clay loam, San Antonio	5.8	8	1	− 3	14	12	35	10	11	19	19	− 7
Orangeburg clay, Maroney's farm	8.6	− 3	1	17	− 3	12	7	14	4	5	29	5
Orangeburg fine sandy loam, Crockett	8.3	......	.....	67	17	60	67	92	24	93	19	58
Orangeburg fine sandy loam, Palestine	9.8	......	.....	30	− 7	37	31	21	7	32	−14	40
Orangeburg fine sandy loam, Nagadoches	8.8	1	6	31	10	31	43	24	16	24	56	15
Orangeburg fine sandy loam, Palestine	11.4	− 7	− 4	11	− 8	10	14	14	−15	9	37	43
IOWA.												
Miscellaneous:												
Wisconsin drift (good)	9.6	−10	15	30	−13	34	42	52	− 5	....	47	......
Wisconsin drift (poor)	7.7	19	34	53	30	49	79	82	17	....	86	......
Iowan drift	9.0	16	25	28	25	47	27	57	36	....	69	......
Missouri loess	11.6	0	2	15	.....	.....	.....	.....	.....	....	5	......
South Iowan loess	5.4	......	.....	.....	35	32	39	41	17	....	−17	47
Kansan till	5.9	7	15	48	12	57	83	73	6	42	24	......
ILLINOIS.												
Marion silt loam	7.7	−13	− 8	− 3	−11	− 4	9	− 8	−13	− 4	48	−12
Red silt loam	7.0	3	8	19	8	17	24	22	16	38	26	45
NEW JERSEY.												
Miscellaneous:												
Norfolk sandy loam, Woodbine	6.0	12	5	20	− 2	16	34	20	2	17	25	14
Norfolk fine sandy loam, Woodbine	6.5	1	1	9	9	22	35	32	7	31	28	42
CONNECTICUT.												
Connecticut Valley area:												
Hartford sandy loam	8.2	......	.....	18	3	− 6	18	3	10	29	14	58
MARYLAND.												
Miscellaneous:												
Leonardtown loam (good)	8.3	16	7	47	.....	41	47	46	10	....	17	......
Leonardtown loam (poor)	6.5	− 7	15	8	.....	0	12	22	1	....	24	89
Muck, peat, and swamp soils:												
Illinois	9.4	16	49	4	39	14	40	25	7	33	45	51
Iowa	15.0	24	26	21	11	− 4	15	20	−14	....	64	......
Wisconsin, Portage County	7.2	42	25	21	51	39	39	47	23	41	51	16
Indiana, Newton County	4.4	−25	61	14	66	− 7	41	100	14	70	40	18
Virginia, Portsmouth	3.2	53	112	69	69	84	75	69	75	97	47	72
Average for type	7.8	22	55	26	47	25	42	52	21	60	49	39

COMPARATIVE EFFICIENCY OF SALTS USED SEPARATELY AND IN COMBINATION.

Table IV, which follows, is primarily for the purpose of showing the wide variation in the aggregate effect of the three fertilizer ingredients when used separately as compared with their efficiency when used together. This table gives the percentage increase or decrease in growth (the latter indicated by the minus sign) produced by acid phosphate, sulphate of potash, and nitrate of soda used separately; the aggregate increase attributable to these three ingredients; the increase when the three ingredients were combined and the difference between the aggregate and that observed when the same ingredients were used in combination. All soils having complete data for these observations are included, the total number being 190, and the data are arranged in a descending series, beginning with the greatest difference in favor of the sum of the ingredients, until the difference becomes zero, after which the series is ascending and the differences are in favor of the combination. A wide variation is shown in the last column, the difference ranging from a maximum of 165 per cent in favor of the sum of the ingredients to zero and then increasing to a maximum of 72 per cent at the other extreme in favor of the combination.

Of the total number of comparisons (190) there are 71 soils in which the efficiency of the combination exceeded the aggregate of the separate ingredients, 117 soils in which the aggregate of the individual effects exceeds that of the combination, and 2 soils in which the aggregate effect of the single ingredients exactly equals the increase in growth when those ingredients were used in combination. The number of soils that show very wide differences in respect to the aggregate efficiency of the ingredients as compared with the effect when the same ingredients are combined is small, the number increasing greatly as the lesser differences are approached. For example, 60 soils show differences of 9 per cent or less, while for 115 soils the difference is within the limit of 19 per cent. Within this limit of 19 per cent there are 51 soils in which the difference is in favor of the combination and 62 in which it is in favor of the aggregate increase for the same ingredients used separately. (See Table V following.) As a result of averages within these limits, acid phosphate gives an increase of 0.64 per cent, sulphate of potash 6.68 per cent, and nitrate of soda 19 per cent, or a total of 26.32 per cent, as compared with 24.5 per cent as a mean effect of the same ingredients used in combination on the same soils. Within these limits, which includes 60 per cent of the soils, the average efficiency of the ingredients as measured by the growth of the plants is nearly the same whether used separately or in combination. It therefore appears that each ingredient has performed special functions which differ from and are independent of those performed by the others, whether the ingredients are applied separately or in combination.

Of the soils in which the effect of the ingredients in combination differs from the aggregate effect of the same ingredients used separately by 20 per cent or more, 55 are in favor of the ingredients used separately and 20 in favor of their combination. Within the former group of soils there are 15 instances in which the aggregate increase of the ingredients when used separately is more than three times as great as when the same ingredients were used in combination, and 12 instances where the aggregate is less than three times but more than two times as great as when used in combination. Within this group, therefore, the function of the several ingredients is to a considerable degree identical, at least so far as they effect an increase in the growth of plants, and one may be substituted for another to a considerable extent.

Of the soils in which the efficiency of the combination exceeds that of the same ingredients used separately by 20 per cent or more there are only 20. In this group the function of each ingredient is not only different from that of the others, but each is dependent upon the presence of others in order that it may have the greatest effect.

There is no apparent relation either by soil type or locality with this grouping of the soils; neither do the soils of one group appear to be particularly more responsive to the complete fertilizer than those of another. Of 190 observations on each, the individual ingredients give negative results as follows: Acid prosphate 66 times, sulphate of potash 31 times, and nitrate of soda 22 times. The combination of all three ingredients gives a negative result only 9 times, while the aggregate effect of the individual ingredients becomes negative 21 times.

Table V shows the average increase produced by each ingredient, the aggregate increase, and the actual increase when the ingredients were combined for soils in which the aggregate increase from individual ingredients differs within certain limits from that obtained when the same ingredients were combined.

There are ten soils in which each of the three ingredients when used separately gave a greater increase in growth than when all were combined and ten others in which two of the three each equaled or exceeded the gain produced by the three combined. (See Tables VI and VII.) These soils are not confined to particular localities or types, neither are they associated with high or low degree of natural fertility, as may be seen by the wide range in weight of plants on the untreated soils.

TABLE IV.—*Percentage increase in growth attributable to P, K, and N, and the sum of the same, as compared with the observed increase when a mixture of the three fertilizers was applied.*

[Results arranged in descending series, beginning with the greatest actual difference in favor of the sum of the ingredients.]

State.	Locality.	Soil.	Weight of plants on untreated soil.	Increase attributable to—			Sum of P, K, and N.	Increase attributable to PKN.	Difference.
				P.	K.	N.			
			Grams.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Virginia	Portsmouth	Peat	3.2	53	112	69	234	69	165
North Carolina	Edgecombe	Norfolk fine sandy loam.	4.8	44	42	63	149	56	93
Mississippi	Pontotoc County	Lufkin silt loam	5.4	41	44	52	137	50	87
Louisiana	Caddo Parish	Caddo fine sandy loam.	4.4	18	18	86	122	36	86
Texas	Rusk County	Norfolk fine sandy loam.	6.1	31	31	48	110	48	62
Louisiana	Caddo Parish	Norfolk fine sand	3.7	− 3	51	62	110	51	59
North Carolina	Iredell test farm	Cecil clay	4.5	86	34	42	162	105	57
Virginia	Louisa County	Cecil loam	4.6	36	47	75	158	102	56
Louisiana	Caddo Parish	Miller fine sand	7.3	21	26	10	57	1	56
North Carolina	Pinehurst	Portsmouth sand	4.8	42	26	42	110	56	54
Missouri	Crawford County	Clarksville silt loam.	6.6	26	15	17	58	7	51
Iowa	Ames	Peat	15.0	24	26	21	71	20	51
Texas	San Marcos	Crawford silt clay	9.2	20	21	31	72	22	50
North Carolina	New Hanover County.	Norfolk sand	4.1	37	41	122	200	151	49
North Carolina	Blantyre	Porter's sandy loam.	4.5	4	44	20	68	24	44
Illinois	Manito	Muck	9.4	16	49	4	69	25	44
Louisiana	Caddo Parish	Miller fine sand	5.8	12	12	38	62	19	43
Louisiana	Caddo Parish	Caddo fine sandy loam.	6.0	6	17	26	49	8	41
Wisconsin		Muck	7.2	42	25	21	88	47	41
Indiana	Newton County	Marshall loam	7.6	17	22	17	56	16	40
Mississippi	Montgomery County.	Orangeburg fine sandy loam.	7.5	24	20	43	87	48	39
Florida	EscambiaCounty.	Norfolk fine sandy loam.	3.3	24	36	27	87	48	39
Arkansas	Prairie County	Waverly silt loam.	5.0	28	20	18	66	28	38
Texas	San Marcos area	Houston black clay.	7.0	20	21	31	72	35	37
South Carolina	York County	Cecil sandy loam	7.0	40	3	28	71	34	37
New York	Geneseo	Dunkirk clay loam.	8.9	16	29	20	65	28	37
Florida	EscambiaCounty.	Norfolk sand	5.9	5	32	45	82	46	36
Florida	EscambiaCounty.	Norfolk sand	5.4	16	18	13	47	11	36
New York	Genesee County	Dunkirk clay loam.	10.2	11	11	18	40	5	35
Florida	EscambiaCounty.	Norfolk sand	7.2	4	19	33	56	22	34
Georgia	Waycross area	Norfolk fine sandy loam.	7.5	17	28	60	105	73	32
North Carolina	Raleigh	Cecil sandy loam	4.1	20	31	30	81	49	32
Mississippi	Montgomery County.	Lintonia loam	8.5	7	17	29	53	22	31
Arkansas	Prairie County	Acadia silt loam	7.4	22	20	29	71	41	30
Indiana	Newton County	Marshall fine sandy loam.	6.3	5	12	9	26	− 4	30
Georgia	Waycross area	Norfolk sand	5.6	− 4	30	61	87	57	30
Texas	Rusk County	Caddo fine sandy loam.	8.1	12	11	40	63	34	29
Georgia	Waycross area	Norfolk fine sandy loam.	3.9	11	29	74	114	86	28
North Carolina	Tarboro	Norfolk fine sandy loam.	5.3	25	22	42	89	63	26
Texas	San Marcos area	Crawford silt clay	8.8	13	25	30	68	42	26
Arkansas	Prairie County	Crowley silt loam	7.0	0	10	43	53	27	26
Arkansas	Prairie County	Morse clay	11.1	5	13	−3	15	−11	26
Louisiana	Caddo Parish	Norfolk fine sand	5.4	21	19	41	81	56	25
Arkansas	Prairie County	Crowley silt loam	8.1	9	14	2	25	0	25
Iowa	Ames	Wisconsin drift (poor).	7.7	19	34	53	106	82	24
Arkansas	Prairie County	Waverly silt loam.	6.5	15	20	27	62	38	24
Texas	San Marcos	Blanco loam	8.7	17	21	19	57	33	24
Maryland	Leonardtown	Leonardtown loam (good).	8.3	16	7	47	70	46	24
Georgia	Waycross area	Portsmouth fine sand.	5.2	6	21	73	100	77	23
Alabama	Lee County	Norfolk sandy loam.	7.7	12	19	55	86	63	23
Louisiana	Caddo Parish	Caddo fine sandy loam.	5.0	−10	4	33	27	4	23

TABLE IV.—*Percentage increase in growth attributable to P, K, and N, and the sum of the same, etc.*—Continued.

State.	Locality.	Soil.	Weight of plants on untreated soil.	Increase attributable to—			Sum of P, K, and N.	Increase attributable to PKN.	Difference.
				P.	K.	N.			
			Grams.	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*
Texas	Rusk County	Norfolk fine sand.	8.5	14	16	41	71	49	22
Alabama	Ford's farm	Orangeburg clay	9.1	22	24	42	88	67	21
Texas	Rusk County	Norfolk fine sandy loam.	7.5	20	28	38	86	65	21
Indiana	Tippecanoe County.	Miami silt loam	5.6	30	21	28	79	58	21
Louisiana	Caddo Parish	Norfolk fine sandy loam.	5.6	− 3	20	35	52	33	19
North Carolina	Biltmore farm	Porters clay	12.4	11	15	18	44	25	19
North Carolina	Wake County	Tobacco soil	4.7	9	11	28	48	30	18
Louisiana	Caddo Parish	Orangeburg fine sand.	7.4	8	10	21	39	21	18
Ohio	Westerville area	Miami clay loam	6.1	11	5	15	31	13	18
Mississippi	Pontotoc County.	Orangeburg sandy loam.	7.6	17	− 2	28	43	26	17
New Jersey	Woodbine	Norfolk sandy loam.	6.0	12	5	20	37	20	17
Missouri	Scotland County.	Shelby silt loam	9.6	7	24	14	45	28	17
Pennsylvania	Montgomery County.	Lansdale silt loam.	9.9	0	23	1	24	7	17
Georgia	Waycross	Norfolk fine sand.	6.0	5	8	53	66	50	16
Wisconsin	Portage County	Miami sand	6.0	7	15	33	55	39	16
Mississippi	Pontotoc County	Lufkin clay	6.4	8	8	28	44	28	16
Mississippi	Montgomery County.	Memphis silt loam.	7.0	7	9	14	30	14	16
Pennsylvania	Montgomery County.	Penn silt loam	12.3	8	12	8	28	13	15
New York	Binghamton area.	Dunkirk gravelly sandy loam.	6.6	4	1	11	16	1	15
Louisiana	Caddo Parish	Norfolk fine sandy loam.	9.6	− 8	9	13	14	− 1	15
Texas	Rusk County	Caddo fine sandy loam.	8.2	6	2	53	61	47	14
Texas	Nagadoches	Orangeburg fine sandy loam.	8.8	1	6	31	38	24	14
New York		Volusia silt loam	6.6	4	22	10	36	23	13
Iowa		Iowan drift	9.0	16	25	28	69	57	12
New York		Volusia silt loam	4.8	− 2	15	34	47	35	12
Wisconsin	Portage County	Marshall sand	8.4	7	9	31	47	35	12
Virginia	Louisa County	Cecil sandy loam	7.2	24	5	13	42	30	12
Arkansas	Prairie County	Calhoun clay	8.3	12	12	14	38	26	12
New York	Binghamton area.	Dunkirk gravelly loam.	10.6	9	9	1	19	7	12
Georgia	Waycross area	Norfolk fine sandy loam.	7.9	1	5	29	35	24	11
Florida	Escambia County	Norfolk fine sandy loam.	8.4	− 7	14	15	22	11	11
New York	Tompkins County	Dunkirk clay loam.	9.0	0	9	13	22	11	11
Louisiana	Caddo Parish	Norfolk fine sandy loam.	8.7	4	9	7	20	9	11
Wisconsin	Portage County	Miami sandy loam	9.0	4	8	2	14	3	11
Georgia	Waycross area	Norfolk sandy loam.	5.0	0	16	20	36	25	11
North Carolina	New Hanover County.	Portsmouth fine sand.	3.0	13	30	77	120	110	10
North Carolina	Statesville	Iredell clay loam	5.2	7	21	16	44	34	10
Texas	Rusk County	Orangeburg fine sandy loam.	9.2	0	2	34	36	26	10
New York		Volusia silt loam	5.4	2	15	13	30	20	10
Louisiana	Caddo Parish	Norfolk fine sand	5.3	15	21	32	68	59	9
South Carolina	Cherokee County.	Iredell clay loam	9.1	− 3	7	32	36	27	9
Alabama	Lee County	Cecil sandy loam	8.6	1	9	14	24	15	9
Ohio	Strongsville	Miami clay loam		− 4	− 5	12	3	− 6	9
Illinois	Pulaski	Red silt loam	7.0	3	8	19	30	22	8
Wisconsin	Portage County	Miami stony sand.	9.9	6	13	11	30	22	8
Florida	Escambia County.	Portsmouth sand	8.3	2	5	12	19	11	8
South Carolina.	Cherokee County.	Cecil silt loam	6.6	2	1	52	55	48	7
Texas	San Marcos	Houston black clay	7.9	8	8	21	37	30	7
Alabama	King's farm	Orangeburg clay	10.3	3	6	17	26	19	7
South Carolina.	York County	Iredell clay loam	7.7	0	6	19	25	18	7
Wisconsin	Portage County	Marshall gravelly loam.	11.0	− 1	− 2	14	11	4	7
Alabama	Lee County	Norfolk coarse sand.	5.3	− 7	15	48	56	50	6
Arkansas	Prairie County	Acadia silt loam	11.2	0	4	29	33	27	6

TABLE IV.—*Percentage increase in growth attributable to P, K, and N, and the sum of the same, etc.*—Continued.

State.	Locality.	Soil.	Weight of plants on untreated soil.	Increase attributable to—			Sum of P, K, and N.	Increase attributable to PKN.	Difference.
				P.	K.	N.			
			Grams.	*P.ct.*	*P.ct.*	*P.ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Arkansas	Prairie County	Morse clay	10.8	4	− 3	2	3	− 3	6
Georgia	Waycross area	Norfolk sand	6.1	− 2	− 5	36	29	24	5
Texas	Rusk County	Orangeburg fine sand.	7.5	− 7	20	31	44	40	4
Virginia	Hanover County	Norfolk sandy loam.	7.5	3	11	20	34	30	4
Georgia	Waycross area	Norfolk fine sand	6.1	7	15	55	77	74	3
Arkansas	Prairie County	Acadia silt loam	7.3	1	7	10	18	15	3
Pennsylvania	Montgomery County.	Hagerstown loam.	10.3	13	− 2	1	12	9	3
Tennessee	Henderson County.	Lexington silt loam.	7.5	1	1	36	38	36	2
North Carolina	Asheville	Porters clay	5.8	− 6	− 2	29	21	19	2
Texas	San Marcos area	Houston black clay	8.9	0	4	15	19	17	2
Missouri	Crawford County.	Clarksville stony loam.	14.6	4	3	− 2	5	3	2
Texas	Maroney's farm	Orangeburg clay	8.6	− 3	1	17	15	14	1
New York	Tompkins County	Dunkirk loam	8.4	− 4	2	15	13	12	1
Indiana	Tippecanoe County.	Marshall loam	7.5	− 3	2	7	6	6	0
Arkansas	Prairie County	Morse clay	8.8	− 9	8	1	0	0	0
Arkansas	Prairie County	Crowley silt loam	10.1	− 1	3	0	2	3	1
Indiana	Tippecanoe County.	Marshall silt loam.	7.2	4	1	6	11	12	1
Arkansas	Prairie County	Acadia silt loam	9.0	0	11	6	17	18	1
North Carolina.	New Hanover County.	Norfolk fine sandy loam.	7.3	3	3	22	28	29	1
New York	Tompkins County	Dunkirk clay loam	4.5	−18	4	55	41	42	1
Ohio	Westerville area	Miami loam	8.6	− 8	3	− 2	− 7	− 5	2
Arkansas	Prairie County	Waverly silt loam.	7.8	− 7	9	− 7	− 5	− 3	2
South Carolina.	Cherokee County	Cecil fine sandy loam.	5.9	− 3	7	46	50	52	2
North Carolina.	Statesville	Cecil clay (good)	8.8	0	− 2	− 4	− 6	− 4	2
Texas	Galveston	Galveston clay	11.2	−14	−12	3	−23	−20	3
Texas	Rusk County	Susquehanna fine sandy loam.	7.0	− 3	0	9	6	9	3
Texas	Rusk County	Norfolk fine sand	7.8	− 4	8	21	25	28	3
Kentucky	McCracken County.	Memphis silt loam.	5.0	− 3	3	39	39	42	3
Alabama	Lee County	Norfolk sand	6.8	9	10	40	59	62	3
Iowa	Leon	Kansan till	5.9	7	15	48	70	73	3
Louisiana	Caddo Parish	Caddo fine sandy loam.	8.8	− 7	5	7	5	9	4
Texas	San Antonio	Houston black clay loam.	5.8	8	1	− 3	6	10	4
North Carolina.	Statesville	Cecil clay (poor)	8.8	− 1	1	0	0	5	5
New York	Tompkins County.	Miami stony loam.	9.6	4	1	1	6	11	5
Georgia	Waycross	Norfolk sandy loam.	6.5	11	15	54	80	85	5
Arkansas	Prairie County	Crowley silt loam	7.1	− 8	0	9	1	7	6
Maryland	Leonardtown	Leonardtown loam (poor).	6.5	− 7	15	8	16	22	6
Texas	Rusk County	Norfolk fine sand	8.6	5	6	19	30	36	6
Alabama	Rawles's farm	Orangeburg sandy loam.	8.1	6	− 5	4	5	12	7
Texas	San Marcos area	Houston black clay	8.1	− 4	− 5	21	12	19	7
Alabama	Lee County	Norfolk sand	4.7	− 1	− 1	30	28	35	7
South Carolina.	Cherokee County	Cecil sandy loam	6.9	−12	28	35	51	58	7
Mississippi	Montgomery County.	Memphis silt loam.	8.6	−13	6	12	5	13	8
Louisiana	Caddo Parish	Orangeburg fine sandy loam.	6.5	3	3	0	6	15	9
Texas	San Marcos area	Crawford silt clay.	9.2	− 7	2	19	14	23	9
South Carolina.	Cherokee County.	Cecil clay	7.4	− 4	− 6	36	26	35	9
Virginia	Pocahontas field	Cecil clay	11.7	− 3	4	− 3	− 2	9	11
Mississippi	Pontotoc County.	Monroe silt loam	8.0	− 4	− 6	13	3	14	11
New York	Binghamton area.	Wabash loam	10.6	− 1	11	5	15	26	11
Missouri	Crawford County.	Wabash silt loam	7.6	−11	1	− 3	−13	− 1	12
Georgia	Waycross	Norfolk sand	5.5	− 9	24	45	60	72	12
South Carolina.	St. Matthews	Orangeburg sandy loam.	11.8	0	− 2	15	13	26	13
Texas	Palestine	Orangeburg fine sandy loam.	11.4	− 7	− 4	11	0	14	14

TABLE IV.—*Percentage increase in growth attributable to P, K, and N, and the sum of the same, etc.*—Continued.

State.	Area.	Soil.	Weight of plants on untreated soil.	Increase attributable to—			Sum of P, K, and N.	Increase attributable to PKN.	Difference.
				P.	K.	N.			
			Grams.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Pennsylvania	Montgomery County.	Chester loam	7.8	0	9	4	13	27	14
North Carolina	Union County	Silt loam	4.6	−4	0	32	28	42	14
Alabama	Lee County	Norfolk sandy loam.	6.1	−14	4	42	32	46	14
North Carolina	New Hanover County.	Norfolk fine sand	6.4	3	9	37	49	63	14
Ohio	Westerville area	Miami black clay loam.	8.3	−11	6	−2	−7	8	15
Florida	Escambia County	Norfolk fine sandy loam.	5.5	10	12	−5	17	32	15
Illinois		Marion silt loam	7.7	−13	−8	−3	−24	−8	16
Louisiana	Caddo Parish	Orangeburg fine sandy loam.	5.0	0	6	10	16	32	16
Wisconsin	Portage County	Portage silt loam	8.7	2	−16	−2	−16	1	17
Alabama	Lee County	Norfolk coarse sand.	6.4	−12	0	20	8	25	17
Iowa		Wisconsin drift (good).	9.6	−10	15	30	35	52	17
Georgia	Waycross	Portsmouth fine sand.	5.5	2	18	33	53	71	18
Mississippi	Montgomery County.	Memphis silt loam.	10.6	−13	−3	−2	−18	1	19
Indiana	Newton County	Clyde fine sand	12.6	−21	−2	−14	−37	−17	20
Mississippi	Montgomery County.	Memphis silt loam.	9.5	−16	−9	0	−25	−5	20
New Jersey	Woodbine	Norfolk fine sandy loam.	6.5	1	1	9	11	32	21
Georgia	Waycross	Norfolk sandy loam.	7.0	−7	14	36	43	64	21
Virginia	Hanover County	Wickham sandy loam.	7.5	−3	5	11	13	36	23
Alabama	Marion	Orangeburg sandy loam.	4.8	14	7	25	46	69	23
Georgia	Waycross	Portsmouth fine sand.	5.2	1	15	50	66	90	24
North Carolina	Chowan County	Portsmouth silt loam.	4.5	2	19	14	35	62	27
Wisconsin	Portage County	Portage silt loam	10.0	−11	−9	−6	−26	3	29
Mississippi	Montgomery County.	Memphis silt loam.	10.2	−3	−2	−15	−20	12	32
Alabama	Lee County	Cecil sandy loam	5.6	−11	−7	29	11	43	32
Mississippi	Pontotoc County.	Orangeburg clay	6.6	−9	3	18	12	45	33
Georgia	Waycross	Norfolk fine sand	7.4	−9	−8	−3	−20	14	34
Mississippi	Montgomery County.	Memphis silt loam.	11.2	−10	−7	−11	−28	8	36
Texas	Rusk County	Orangeburg fine sandy loam.	9.2	−12	−6	14	−4	36	40
Louisiana	Caddo Parish	Norfolk fine sandy loam.	7.9	1	−5	−10	−14	35	49
Indiana	Newton County	Muck	4.4	−25	61	14	50	100	50
South Carolina	York County	Cecil sand	3.9	−15	−8	26	3	54	51
Louisiana	Caddo Parish	Orangeburg fine sand.	5.0	−22	−10	−10	−42	28	70
Rhode Island	Kingston	Miami silt loam	3.6	−8	−19	−14	−41	31	72

TABLE V.—*Average percentage increase in growth attributable to P, K, and N and the aggregate increase of the same salts used individually as compared with the actual increase when the same salts were used together, averages being for the soils in which the difference between the aggregate and actual increase is within limits indicated in the first column.*

Range of difference.	Number of soils.	Green weight of plants.	Increase attributable to—			Sum of P, K, and N.	Increase attributable to mixture of PKN.	Difference.
			P.	K.	N.			
Per cent.		*Grams.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
60+	5	4.8	37	49	64	150	52	98
50-59	8	7.0	31	31	38	100	46	54
40-49	7	6.4	19	30	35	84	41	43
30-39	16	6.7	16	22	31	69	34	35
20-29	19	7.3	13	19	38	70	46	24
10-19	35	7.6	6	12	22	40	26	14
0-9	28	8.3	1	5	22	28	23	5
9-0	32	7.6	− 2	4	17	19	23	− 4
19-10	20	7.9	− 5	4	14	13	28	−15
29-20	9	7.5	− 4	4	14	14	37	−23
39-30	5	8.2	− 8	−5	4	−9	24	−33
49-40	2	8.6	− 6	−5	2	−9	36	−45
50+	4	4.2	−18	6	4	−8	53	−61

TABLE VI.—*Ten soils in which percentage increase attributable to each ingredient is greater than that produced when all are combined.*

State.	Locality.	Soil type.	Weight of plants grown on untreated soil.	Increase attributable to—			Sum of PKN.	Increase attributable to mixture of PKN.	Difference.
				P.	K.	N.			
			Grams.	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*
Louisiana	Caddo Parish	Miller fine sand	7.3	21	26	10	57	1	56
Iowa	Ames	Peat	15.0	24	26	21	71	20	51
Missouri	Crawford County	Clarksville silt loam.	6.6	26	15	17	58	7	51
Indiana	Newton County	Marshall loam	7.6	17	22	17	56	16	40
Florida	Escambia County	Norfolk sand	5.4	16	18	13	47	11	36
New York	Geneseo	Dunkirk clay loam.	10.2	11	11	18	40	5	35
Indiana	Newton County	Marshall fine sandy loam.	6.3	5	12	9	26	− 4	30
Arkansas	Prairie County	Morse clay	11.1	5	13	−3	15	−11	26
Arkansas	Prairie County	Crowley silt loam.	8.1	9	14	2	25	0	25
New York	Binghamton area.	Dunkirk gravelly sandy loam.	6.6	4	1	11	16	1	15
	Average		8.4	14	16	11	41	5	36

Table VII.—*Ten soils in which two of the three ingredients each produced a greater increase than when all three were combined.*

State.	Locality.	Soil type.	Weight of plants grown on untreated soil.	Increase attributable to—			Sum of PKN.	Increase attributable to mixture of PKN.	Difference.
				P.	K.	N.			
			Grams.	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*
Virginia	Portsmouth	Peat	3.2	53	112	69	234	69	165
Louisiana	Caddo Parish	Norfolk fine sand	3.7	– 3	51	62	110	51	59
Louisiana	Caddo Parish	Caddo fine sandy loam.	6.0	6	17	26	49	8	41
Louisiana	Caddo Parish	Caddo fine sandy loam.	5.0	–10	4	33	27	4	23
Louisiana	Caddo Parish	Norfolk fine sandy loam.	9.6	– 8	9	13	14	– 1	15
New York	Binghamton area	Dunkirk gravelly loam.	10.6	9	9	1	19	7	12
Florida	Escambia County	Norfolk fine sandy loam.	8.4	– 7	14	15	22	11	11
Wisconsin	Portage County	Miami sandy loam.	9.0	4	8	2	14	3	11
Arkansas	Prairie County	Morse clay	10.8	4	– 3	2	3	– 3	6
Missouri	Crawford County	Clarksville stony loam.	14.6	4	3	– 2	5	3	2
	Average		8.1	5	23	22	50	15	35

NITRATE OF SODA ALONE AND WITH OTHER SALTS.

A study of Table IV shows that in 66 per cent of the instances nitrate of soda when used alone has produced an increase of growth which equals or exceeds that produced by either sulphate of potash or acid phosphate.

A tabulation of the data for nitrate of soda and of combinations in which it enters shows that the nitrate of soda has a marked beneficial effect on the majority of soils which on an average is not increased by the addition of acid phosphate. A comparison of the nitrate with the nitrate-phosphate column shows a difference in favor of the former in slightly more than half of the comparisons. The average of these two columns shows a difference of less than one-tenth of 1 per cent.

Nitrate of soda when supplemented with sulphate of potash gives an increase in growth which in 74 per cent of the instances equals or exceeds that produced by nitrate of soda alone, the average result being 8.5 per cent in favor of the combination. When this nitrogen-potash combination is still further supplemented by acid phosphate there is on an average no additional increase in growth. In fact the instances in which the nitrogen-potash combination equals or exceeds that of the complete fertilizer are slightly in the majority. The tabulation above mentioned is not published, but the same facts may be gathered by careful study of those columns in Table III, which give the results for nitrogen and all combinations into which it enters.

SULPHATE OF POTASH ALONE AND WITH OTHER SALTS.

Sulphate of potash when supplemented by acid phosphate produced an increase in growth, which in 50 per cent of the soils exceeded that produced by potash alone, the average increase being one-tenth of 1 per cent in favor of the combination. When the potash salt is combined with nitrate of soda there is a marked increase in growth over that produced by potash alone, which, on the average, is not further increased by the addition of acid phosphate. In 86 per cent of the soils the effect of potash combined with nitrogen has equaled or exceeded the effect of potash alone. These facts are brought out by a study of the columns in Table III, in which potash occurs, omitting all soils for which the data for this salt and all its combinations are incomplete.

ACID PHOSPHATE ALONE AND WITH OTHER SALTS.

Referring to Table IV, the striking fact is the large number of instances in which acid phosphate gives a small or negative effect. The efficiency is quite regularly increased (see all columns of Table III in which phosphate enters) as each fertilizer salt is added, the exceptions to this being mostly for those soils in which the efficiency of the complete fertilizer as a whole becomes quite small or is negative.

In the life and economy of the plant, phosphates are generally recognized to be instrumental chiefly in the production of seed or fruit, and have a tendency to hasten maturity, and may influence the color and quality of the fruit. It is also known that plants do not absorb extraneous phosphates during the very early stages of growth. From the standpoint of the requirements of the plant, no response would be expected from the phosphates, and it is, therefore, not strange that in many instances a small or negative effect has resulted from their application. It should be borne in mind, however, that this is not a study of the plant's requirements, but a study of the fertility of the soil as affected by fertilizers and that the plants have been used merely as the indicator of the degree to which fertility has been affected by the various applications. It is now contended that aside from the direct action that various salts have on the growth and economy of the plant, they may also act directly on the soil, thereby increasing its fertility in a way not fully understood.

An inspection of the tables will show that while small and negative effects have often resulted from the phosphate, there are 55 soils in which the increase in growth attributable to this salt when used alone has ranged from 10 to 50 per cent and in two instances even more.

LIME ALONE AND WITH FERTILIZER SALTS.

Table VIII shows the increase in growth attributable to lime, to a complete fertilizer with and without lime, to manure, and to cowpea vines with lime. The soils are arranged in a descending series as determined by the efficiency of the complete fertilizer without lime. Lime alone shows quite a marked effect in the majority of the soils, and while its efficiency corresponds in a general way with that of a complete fertilizer there are numerous exceptions to this. The lime may have little or no effect where the fertilizer is markedly beneficial. For example, in the upper portion of the table where the figures for the complete fertilizer range from 50 to 75 per cent increase in growth there are 8 soils on which lime gives less than 10 per cent increase, while in the lower portion of the table where the complete fertilizer does not exceed 11 per cent there are 7 instances where the increase in growth attributable to lime exceeds 30 per cent. As a rule, the efficiency of the complete fertilizer has been appreciably increased by the addition of lime. There seems to be little evidence in support of the contention sometimes made that the benefits due to lime are attributable to its favorable action on nitrification.

A study of Table IX, which summarizes the results of Table VIII and all data for the same soils in Table III—i. e., gives the mean percentage increase in growth attributable to the several fertilizer salts and combinations for groups of soils in which the efficiency of a complete fertilizer falls within certain limits as given in the second column—shows that as the efficiency of a complete fertilizer declines there is a corresponding decline in the effect of practically all ingredients and combinations. This is equally as true for manure or for potash and phosphate as it is for nitrate of soda and lime, so that the parallel decline in the lime and nitrate columns in the table loses significance. Of the soils in Table VIII, where the efficiency of a complete fertilizer is not less than 25 nor more than 75 per cent, there are 17 in which the efficiency of lime exceeds 35 per cent and 31 in which it is 10 per cent or less. As a result of averages of these two groups of soils, we get the following results: Seventeen soils (lime giving increase of 35 per cent or more) average efficiency, lime 63, N 35, NKP 49; 31 soils (lime giving increase of 10 per cent or less) lime 4, N 24, NKP 40. The effect of nitrogen is obtained from Table III.

The difference in the efficiency of lime is here very marked, dropping from an average of 63 per cent for the 17 soils to only 4 per cent for the 31 soils. The relative decline in the effect of nitrate of soda and the complete fertilizer, however, is small, being from 35 to 24 for the former and 49 to 40 for the latter.

TABLE VIII.—*Weight of plants on the untreated soil and the percentage increase in growth produced by lime, a complete fertilizer with lime, a complete fertilizer, manure, and cowpea vines with lime.*

State.	Locality.	Soil.	Weight of plants, untreated soil.	Increase attributable to—				
				L.	NPKL.	NPK.	M.	CvL.
			Grams.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
North Carolina...	New Hanover County.	Norfolk sand.......	4.1	66	154	151	254	144
North Carolina..	New Hanover County.	Portsmouth fine sand.	3.0	70	173	110	130	230
North Carolina...	Iredell test farm...	Cecil clay...........	4.5	45	105	105	90	......
Virginia.........	Louisa County....	Cecil loam..........	4.6	71	153	102	63	158
Indiana.........	Newton County...	Peat................	4.4	14	70	100	40	18
Georgia..........	Waycross area....	Portsmouth fine sand.	5.2	92	153	90	219	175
Georgia..........	Waycross area....	Norfolk fine sandy loam.	3.9	64	106	86	150	176
Georgia..........	Waycross area....	Norfolk sandy loam	6.5	35	100	85	109	109
Iowa.............	Ames............	Wisconsin drift (poor).	7.7	17	....	82	86	......
Georgia..........	Waycross area....	Portsmouth fine sand.	5.2	29	117	77	150	148
Georgia..........	Waycross area....	Norfolk fine sand....	6.1	34	84	74	102	107
Georgia..........	Waycross area....	Norfolk fine sandy loam.	7.5	40	89	73	113	113
Iowa.............	Leon.............	Kansan till.........	5.9	6	42	73	24	......
Georgia..........	Waycross area....	Norfolk sand........	5.5	64	109	72	124	118
Georgia..........	Waycross area....	Portsmouth fine sand..	5.5	20	75	71	64	109
Alabama.........	Marion...........	Orangeburg sandy loam.	4.8	12	69	69	37	60
Virginia.........	Portsmouth......	Peat................	3.2	75	97	69	47	72
Alabama.........	Marion...........	Orangeburg clay...	9.1	20	55	67	49	35
Texas............	Rusk County......	Norfolk fine sandy loam.	7.5	21	64	65	105	62
Georgia..........	Waycross area....	Norfolk sandy loam.	7.0	0	57	64	103	94
North Carolina..	New Hanover County..	Norfolk fine sand....	6.4	16	70	63	94	37
North Carolina.	Tarboro..........	Norfolk fine sandy loam.	3.0	1	70	63	38	78
Alabama.........	Lee County.......	Norfolk sandy loam.	7.7	19	87	63	61	164
North Carolina..	Chowan County..	Portsmouth silt loam.	4.5	19	57	62	46	74
Alabama.........	Lee County.......	Norfolk sand........	6.8	57	103	62	107	160
Louisiana........	Caddo Parish.....	Norfolk fine sand ...	5.3	9	74	59	28	80
Indiana..........	Tippecanoe County.	Miami silt loam.....	5.6	17	35	58	71	30
South Carolina...	Cherokee County..	Cecil sandy loam....	6.9	4	65	58	71	5
Georgia..........	Waycross area....	Norfolk sand........	5.6	20	121	57	114	132
Iowa.............	Blackhawk County.	Iowan drift.........	9.0	36	....	57	69	......
North Carolina..	Edgecombe.......	Norfolk fine sandy loam.	4.8	25	77	56	66	......
North Carolina..	Pinehurst.........	Portsmouth sand...	4.8	26	46	56	41	45
Louisiana........	Caddo Parish.....	Norfolk fine sand ...	5.4	39	80	56	92	98
South Carolina...	York County.....	Cecil sand..........	3.9	8	51	54	90	60
South Carolina...	Cherokee County..	Cecil fine sandy loam.	5.9	29	68	52	88	123
Iowa.............	Ames............	Wisconsin drift (good).	9.6	− 5	....	52	47	......
Louisiana........	Caddo Parish.....	Norfolk fine sand ...	3.7	41	113	51	146	195
Alabama.........	Lee County.......	Norfolk coarse sand.	5.3	5	70	50	59	101
Mississippi.......	Pontotoc area....	Lufkin silt loam.....	5.4	63	56	50	37	78
Georgia..........	Waycross area....	Norfolk fine sand ...	6.0	27	32	50	113	107
North Carolina..	Raleigh..........	Cecil sandy loam....	4.1	52	103	49	53	54
Texas............	Rusk County.....	Norfolk fine sand ...	8.5	21	55	49	86	48
South Carolina...	Cherokee County..	Cecil silt loam.......	6.6	39	56	48	81	74
Florida..........	Escambia County	Norfolk fine sandy loam.	3.3	136	130	48	90	136
Mississippi......	Montgomery County.	Orangeburg fine sandy loam.	7.5	24	64	48	60	60
Texas...........	Rusk County.....	Norfolk fine sandy loam.	6.1	40	41	48	48	80
Texas...........	Rusk County.....	Caddo fine sandy loam.	8.2	7	47	47	61	57
Wisconsin.......	Portage County..	Muck..............	7.2	23	41	47	51	16

TABLE VIII.—*Weight of plants on the untreated soil and the percentage increase in growth produced by lime, etc.*—Continued.

State.	Locality.	Soil.	Weight of plants, untreated soil.	Increase attributable to—				
				L.	NPKL.	NPK.	M.	CvL.
			Grams.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Florida	Escambia County	Norfolk sand	5.9	24	55	46	94	97
Alabama	Lee County	Norfolk sandy loam.	6.1	11	64	46	42	104
Mississippi	Pontotoc County.	Orangeburg clay	6.6	– 3	47	45	18	32
Alabama	Lee County	Cecil sandy loam	5.6	13	52	43	43	......
New York	Tompkins County.	Dunkirk clay loam.	4.5	29	....	42	33	54
North Carolina	Union County	Silt loam	4.6	4	51	42	28	......
Kentucky	McCracken County.	Memphis silt loam.	5.0	18	48	42	70	2
Texas	San Marcos area	Crawford silt clay	8.8	24	46	42	56	11
Arkansas	Prairie County	Acadia silt loam	7.4	23	48	41	31	38
Texas	Rusk County	Orangeburg fine sand.	7.5	8	60	40	80	68
Wisconsin	Portage County	Miami sand	6.0	7	43	39	80	– 4
Arkansas	Prairie County	Waverly silt loam.	6.5	61	55	38	38	54
Virginia	Louisa County	Wickham sandy loam.	7.5	9	35	36	31	–12
Tennessee	Henderson County.	Lexington silt loam.	7.5	5	57	36	72	17
Louisiana	Caddo Parish	Caddo fine sandy loam.	4.4	18	52	36	20	186
Texas	Rusk County	Norfolk fine sand.	8.6	10	26	36	61	37
Texas	Rusk County	Orangeburg fine sandy loam.	9.2	13	39	36	68	53
Wisconsin	Portage County	Marshall sand	8.4	11	8	35	34	3
New York	....	Volusia silt loam	4.8	15	62	35	81	......
South Carolina	Cherokee County.	Cecil clay	7.4	4	44	35	42	12
Alabama	Lee County	Norfolk sand	4.7	50	135	35	108	143
Louisiana	Caddo Parish	Norfolk fine sandy loam.	7.9	2	56	35	18	47
Texas	San Marcos area	Houston black clay.	7.0	17	42	35	10	38
North Carolina	Statesville	Iredell clay loam	5.2	– 1	28	34	33	......
South Carolina	York County	Cecil sandy loam	7.0	33	41	34	76	58
Texas	Rusk County	Caddo fine sandy loam.	8.1	17	36	34	62	40
Louisiana	Caddo Parish	Norfolk fine sandy loam.	5.6	28	54	33	54	52
Texas	San Marcos area	Blanco loam	8.7	20	21	33	28	37
Florida	Escambia County.	Norfolk fine sandy loam.	5.5	45	82	32	32	85
Louisiana	Caddo Parish	Orangeburg fine sandy loam.	5.0	0	44	32	34	96
New Jersey	Woodbine	Norfolk fine sandy loam.	6.5	7	31	32	28	42
Rhode Island	Kingston	Miami silt loam	3.6	133	111	31	39	....
Virginia	Louisa County	Cecil sandy loam	7.2	5	39	30	25	57
Virginia	Hanover County.	Norfolk sandy loam	7.5	– 1	47	30	44	– 8
North Carolina	Wake County	Tobacco soil	4.7	11	16	30	.....	......
Texas	San Marcos area	Houston black clay.	7.9	15	21	30	30	42
North Carolina	New Hanover County.	Norfolk fine sandy loam.	7.3	8	31	29	57	34
Missouri	Scotland County	Shelby silt loam	9.6	11	28	28	69	30
New York	Geneseo	Dunkirk clay loam	8.9	19	22	28	17	28
Mississippi	Pontotoc area	Lufkin clay	6.4	6	31	28	9	48
Louisiana	Caddo Parish	Orangeburg fine sand.	5.0	12	15	28	114	124
Arkansas	Prairie County	Waverly silt loam.	5.0	104	150	28	10	132
Texas	Rusk County	Norfolk fine sand	7.8	3	60	28	103	69
Pennsylvania	Montgomery County.	Chester loam	7.8	4	33	27	13	8
South Carolina	Cherokee County.	Iredell clay loam	9.1	14	42	27	36	7
Arkansas	Prairie County	Crowley silt loam	7.0	43	71	27	64	80
Arkansas	Prairie County	Acadia silt loam	11.2	12	33	27	46	27
South Carolina	St. Matthews	Orangeburg sandy loam.	11.8	19	28	26	25	17
New York	Binghamton County.	Wabash loam	10.6	10	15	26	31	10
Mississippi	Pontotoc County.	Orangeburg sandy loam.	7.6	6	39	26	25	24
Arkansas	Prairie County	Calhoun clay	8.3	18	27	26	4	13
Texas	Rusk County	Orangeburg fine sandy loam.	9.2	12	37	26	37	66
North Carolina	Biltmore	Porters clay	12.4	31	26	25	61	24

TABLE VIII.—*Weight of plants on the untreated soil and the percentage increase in growth produced by lime, etc.*—Continued.

State.	Locality.	Soil.	Weight of plants, untreated soil.	Increase attributable to—				
				L.	NPKL.	NPK.	M.	CvL.
			Grams.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Georgia	Waycross area	Norfolk sandy loam	5.0	− 9	43	25	54	42
Alabama	Lee County	Norfolk coarse sand	6.4	22	23	25	33	41
Illinois	Manito	Muck	9.4	7	33	25	45	51
North Carolina	Blantyre	Porters sandy loam	4.5	43	22	24	61	31
Georgia	Waycross area	Norfolk sand	6.1	34	55	24	77	65
Georgia	Waycross area	Norfolk fine sandy loam.	7.9	22	35	24	96	67
Texas	Nacogdoches	Orangeburg fine sandy loam.	8.8	16	24	24	56	15
New York	....	Volusia silt loam	6.6	8	15	23	77	13
Texas	San Marcos area	Crawford silt clay	9.2	4	31	23	14	34
Wisconsin	Portage County	Miami stony sand	9.9	− 3	19	22	47	8
Florida	Escambia County	Norfolk sand	7.2	29	23	22	66	65
Mississippi	Montgomery County.	Lintonia loam	8.5	24	16	22	30	48
Texas	San Marcos area	Crawford silt clay	9.2	20	42	22	40	52
Illinois	Pulaski County	Red silt loam	7.0	16	38	22	26	45
Louisiana	Caddo Parish	Orangeburg fine sand.	7.4	20	28	21	15	28
New York	Ithaca	Volusia silt loam	5.4	9	32	20	51	29
New Jersey	Woodbine	Norfolk sandy loam	6.0	2	17	20	25	14
Iowa	Ames	Muck	15.0	−14	....	20	64	......
North Carolina	Asheville	Porters clay	5.8	10	53	19	9	16
Alabama	Perry County	Orangeburg clay	10.3	16	35	19	32	26
Louisiana	Caddo Parish	Miller fine sand	5.8	22	34	19	81	48
Texas	San Marcos area	Houston black clay.	8.1	6	26	19	25	32
South Carolina	York County	Iredell clay loam	7.7	3	17	18	51	19
Arkansas	Prairie County	Acadia silt loam	9.0	−11	41	18	32	21
Texas	San Marcos area	Houston black clay.	8.9	5	23	17	8	23
Indiana	Newton County	Marshall loam	7.6	22	21	16	77	34
Alabama	Lee County	Cecil sandy loam	8.6	10	28	15	.....	58
Louisiana	Caddo Parish	Orangeburg fine sandy loam.	6.5	7	15	15	20	26
Arkansas	Prairie County	Acadia silt loam	7.3	14	37	15	7	16
Georgia	Waycross area	Norfolk fine sand	7.4	6	25	14	28	36
Mississippi	Pontotoc County.	Monroe silt loam	8.0	9	18	14	29	39
Texas	Nacogdoches	Orangeburg clay	8.6	4	5	14	29	5
Texas	Palestine	Orangeburg fine sandy loam.	11.4	−15	9	14	37	43
Mississippi	Montgomery County.	Memphis silt loam	7.0	13	17	14	36	40
Ohio	Westville area	Miami clay loam	6.1	7	11	13	15	45
Pennsylvania	Montgomery County.	Penn silt loam	12.3	− 8	4	13	24	36
Mississippi	Montgomery County.	Memphis silt loam	8.6	6	9	13	6	34
Indiana	Tippecanoe County.	Marshall silt loam	7.2	− 7	6	12	−2	4
New York	Tompkins County	Dunkirk loam	8.4	− 7	11	12	46	0
Alabama	Perry County	Orangeburg sandy loam.	8.1	21	17	12	17	20
Mississippi	Montgomery County.	Memphis silt loam	10.2	1	20	12	18	28
New York	Tompkins County	Dunkirk clay loam	9.0	−14	12	11	68	− 5
New York	Tompkins County	Miami stony loam	9.6	0	7	11	36	26
Florida	Escambia County	Portsmouth sand	8.3	48	48	11	47	35
Florida	Escambia County	Norfolk sand	5.4	46	74	11	83	107
Florida	Escambia County	Norfolk fine sandy loam.	8.4	35	14	11	32	51
Texas	San Antonio	Houston black clay loam.	5.8	11	19	10	19	− 7
Pennsylvania	Montgomery County.	Hagerstown loam	10.3	6	23	9	20	29
Louisiana	Caddo Parish	Caddo fine sandy loam.	8.8	8	14	9	6	41
Louisiana	Caddo Parish	Norfolk fine sandy loam.	8.7	0	30	9	9	25
Texas	Rusk County	Susquehanna fine sandy loam.	7.0	−11	26	9	29	56
Ohio	Westerville area	Miami black clay loam.	8.3	1	11	8	22	5
Mississippi	Montgomery County.	Memphis silt loam	11.2	0	−3	8	5	9

Table VIII.—*Weight of plants on the untreated soil and the percentage increase in growth produced by lime, etc.*—Continued.

State.	Locality.	Soil.	Weight of plants, untreated soil.	Increase attributable to—				
				L.	NPKL.	NPK.	M.	CvL.
			Grams.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Louisiana.......	Caddo Parish.....	Caddo fine sandy loam.	6.0	19	16	8	79	23
Missouri.........	Crawford County.	Clarksville silt loam	6.6	14	1	7	43	32
Pennsylvania....	Montgomery County.	Lansdale silt loam..	9.9	19	17	7	9	30
New York.......	Binghamton area.	Dunkirk gravelly loam.	10.6	− 3	−11	7	20	− 9
Arkansas.........	Prairie County...	Crowley silt loam...	7.1	36	60	7	19	38
Indiana..........	Tippecanoe County.	Marshall loam......	7.5	− 3	7	6	42	− 2
New York.......	Geneseo..........	Dunkirk clay loam..	10.2	8	0	5	17	21
Wisconsin......	Portage County..	Marshall gravelly loam.	11.0	2	3	4	36	14
Louisiana.......	Caddo Parish.....	Caddo fine sandy loam.	5.0	8	72	4	44	148
Wisconsin......	Portage County..	Miami sandy loam..	9.0	4	21	3	29	12
Wisconsin.......	Portage County..	Portage silt loam...	10.0	5	10	3	21	10
Missouri........	Crawford County.	Clarksville stony loam.	14.6	− 3	− 2	3	−10	13
Arkansas........	Prairie County...	Crowley silt loam...	10.1	2	5	3	7	9
Wisconsin.......	Portage County..	Portage silt loam...	8.7	9	−14	1	42	−14
New York.......	Binghamton area.	Dunkirk gravelly sandy loam.	6.6	26	27	1	29	69
Mississippi......	Montgomery Co..	Memphis silt loam..	10.6	− 1	16	1	− 4	6
Louisiana.......	Caddo Parish	Miller fine sand.....	7.3	14	16	1	43	36
Arkansas........	Prairie County...	Crowley silt loam...	8.1	46	33	0	18	42
Arkansas........	Prairie County...	Morse clay.........	8.8	6	− 7	0	6	22
Missouri.........	Crawford County.	Wabash silt loam...	7.6	0	2	− 1	23	24
Louisiana.......	Caddo Parish	Norfolk fine sandy loam.	9.6	6	19	− 1	22	1
Arkansas........	Prairie County ...	Morse clay.........	10.8	2	4	− 3	4	9
Arkansas........	Prairie County ...	Waverly silt loam..	7.8	37	40	− 3	18	41
Indiana..........	Newton County..	Marshall fine sandy loam.	6.3	−12	− 1	− 4	60	− 2
North Carolina..	Statesville........	Cecil clay (good)....	8.8	5	....	− 4	9	......
Ohio.............	Westerville area..	Miami loam........	8.6	2	2	− 5	48	15
Mississippi......	Montgomery County.	Memphis silt loam..	9.5	− 5	3	− 5	− 5	11
Ohio.............	Strongsville......	Miami clay loam....	....	30	....	− 6	9	......
Illinois..........	Clinton County...	Marion silt loam....	7.7	−13	− 4	− 8	48	−12
Arkansas.........	Prairie County ...	Morse clay.........	11.1	− 7	− 1	−11	5	4
Indiana..........	Newton County..	Clyde fine sand.....	12.6	−12	− 7	−17	32	− 4
Texas...........	Galveston........	Galveston clay.....	11.2	− 2	− 8	−20	4	31

RELATIVE EFFICIENCY OF ORGANIC AND CHEMICAL MANURES.

An examination of Table VIII shows further the efficiency of manure and cowpea vines with lime as compared with a complete fertilizer with and without lime. In the majority of instances the manure or cowpea vines with lime, or both, have proved superior to the mineral fertilizers. A careful analysis of the results shows that manure and cowpea vines with lime nearly tie for first rank, while the complete fertilizer with lime ranks third, and without lime becomes fourth, or last. The relative number of times that each treatment ranks first on the basis of 100 for the whole is: Manure, 39; cowpea vines with lime, 39; complete fertilizer with lime, 16, and complete fertilizer alone, 6.

RELATIVE EFFICIENCY OF ALL SALTS AND COMBINATIONS WHEN SOILS ARE GROUPED ACCORDING TO EFFICIENCY OF PKN.

Table IX is an aggregation of the results in Table VIII and the results for the same soils in Table III and gives the average percentage increase in growth attributable to each ingredient and combination of ingredients for groups of soils in which the efficiency of a combination of nitrate, potash, and phosphate was within certain limits as given in the second column of the table. It also gives the average green weight of plants grown on the untreated soil for each of the groups as well as the weight produced by a complete fertilizer and the weight produced by the best average treatment for each group which in eight instances is attributable to cowpea vines with lime and in three instances to manure.

The efficiency of the single fertilizers, phosphate, potash, lime and nitrate, with a few exceptions increase in the order named, the phosphate being least effective and the nitrate most effective. In the group of soils for which the efficiency of a complete fertilizer is 60 to 69 per cent, potash outranks lime by 1 per cent, and in the following group it becomes identical with lime. In the last two groups in the table lime outranks the nitrate as well as potash and phosphate. A comparison of the efficiency of the several combinations of fertilizer salts and lime gives the order of efficiency that would be expected from a study of the relative efficiency of the same salts used separately. With a few exceptions, however, the efficiency of the various combinations is a little less than the aggregate efficiency of the same salts when used separately. These exceptions are mostly with the combination of potash and nitrate (KN), which in six out of eleven groups gives a larger percentage increase in growth than the aggregate of the same ingredients used separately. The efficiency order of the combinations, beginning with the smallest, is phosphate-potash (PK), phosphate-nitrate (PN), potash-nitrate (KN), phosphate-potash-nitrate (PKN), and phosphate-potash-nitrate-lime (PKNL). In the four lowest groups of the table, however, the potash-nitrate (KN) combination outranks the complete fertilizer without lime. A comparison of the most efficient fertilizer treatment, viz, that of the three fertilizing salts and lime, with the results obtained with manure and with cowpea vines and lime shows only four groups in which the fertilizer with lime outranks the manure and no instances in which the cowpea vines with lime have failed to outrank the fertilizer with lime. Of the eleven groups, cowpea vines with lime rank first eight times and manure three times.

In the last three columns is given the average green weight of plants on the untreated soil, with a complete fertilizer, and with the best average treatment, for each of the eleven groups of soil. It is noticeable that as there is a regular decrease in the efficiency of the fertilizers there is a corresponding regular increase in the weight of plants produced on the untreated soil. In other words, the lower the producing capacity of the soils the greater their response to fertilizers. The decrease in the efficiency of a complete fertilizer without lime is nearly inversely proportional tô the increase in the weight of plants so that the weight of plants produced by the same fertilizer for any group of soils approaches a constant. The same is essentially true for the best average treatment with a tendency toward the largest plants on the poorer soils, as shown by the maximum weights of plants for the second and third groups from the top of the table under heading of best treatment.

Table IX.—*Average effect of fertilizer salts and combinations by groups according to the efficiency of PKN, also average weight of plants on untreated soil, average weight when treated with PKN, and average weight with best fertilizer treatment.*

Number of soils.	Range of efficiency.	Increase attributable to—											Weight of plants.		
		P.	K.	N.	L.	PK.	PN.	KN.	PKN.	LPKN.	Manure.	Cowpea vines and lime.	Untreated soil.	PKN.	Best treatment.
		P.ct.	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Gms.*	*Gms.*	*Gms.*
5	100+	29	43	66	53	58	75	85	113	131	115	137	4.1	8.7	9.7
4	80–99	10	23	58	52	26	63	85	86	119	141	153	5.8	10.8	14.7
6	70–79	5	20	53	32	23	57	72	73	86	96	119	5.9	10.2	12.9
10	60–69	15	26	40	25	27	50	55	65	73	69	84	6.0	9.9	11.0
15	50–59	11	23	43	23	20	40	48	54	68	69	83	5.8	8.9	10.6
18	40–49	7	15	37	27	18	32	40	45	59	57	62	6.3	9.1	10.2
26	30–39	7	8	23	20	13	21	33	34	48	46	56	6.6	8.8	10.3
35	20–29	5	12	21	17	10	17	27	25	35	45	41	8.0	10.0	11.9
29	10–19	2	4	11	9	4	11	16	14	23	31	29	8.2	9.3	10.7
25	0– 9	1	5	6	8	2	6	12	5	15	24	26	9.0	9.5	11.3
13	−1 to − 20	−7	0	0	2	−7	2	7	−7	4	21	11	9.3	8.7	11.2

RELATIVE EFFICIENCY OF SALTS WHEN USED ALONE AND IN COMBINATION.

In these tests as shown in Table III, beginning on page 15, each of the three salts, acid phosphate, sulphate of potash, and nitrate of soda, has been used separately and in three combinations, thus giving four observations relative to the increase in growth produced by each. For lime there are two observations, while for manure and cowpea vines and lime there is only one observation each. While it is disputed ground as to whether the efficiency of a fertilizer salt should be measured by using it alone or by combining it with all other elements in which the soil may be deficient, many experimenters have adopted the combination as the most reliable means. It seems probable, however, that theoretical considerations, rather than observed results, have led to the adoption of such a system, the idea being that if the soil is deficient in two or more ingredients the full benefits of any one of them can not be obtained in the absence of a sufficiency of the others. While such reasoning seems logical it is not always supported by facts, as may be seen by a study of Table IV. Here there are only 20 soils out of 190 in which this seems to be noticeably true, while there is a much larger number, viz, 50 soils, in which the efficiency of the ingredients used separately is much more marked than when used in combination, and this in spite of the fact that all three of them produce quite marked results. Indeed, when we calculate the average efficiency of the ingredients for all soils we find that each is slightly more efficient when used alone than when in combination with one or more other ingredients.

As an average of many field tests on various crops and in numerous localities the conclusion is that the efficiency of a fertilizer ingredient is about equally as marked whether used alone or in combination with one or more other ingredients. On the less productive soils the tendency is toward a better effect from the ingredient when in combination with other ingredients which are also beneficial. On better soils the tendency is in the other direction.[a] For many individual soils this tendency is as marked under field conditions as it is in the pots.

Numerous bulletins of the Alabama agricultural experiment station report the results of fertilizer tests that were conducted at intervals during the years 1889 to 1900. Of such tests 156 were cooperative experiments with cotton and were carried on in 53 of the 67 counties of the State. The fertilizer materials used per acre consisted of nitrogen derived from 90 pounds of sulphate of ammonia or 96 pounds of nitrate of soda or 200 pounds of cotton-seed meal, potash derived from 150 or 200 pounds of kainit or 64 pounds of muriate of potash, and phosphorus derived from 195 or 200 pounds of dissolved boneblack or 240 pounds of acid phosphate. The three classes of fertilizer were used separately and the three were also combined, each ingredient entering into the combination in the same amount as when used alone. The results are reported in pounds of seed cotton per acre over and above that produced when no fertilizer was used, and the data for each of the three fertilizers when used alone and in combination are complete for 134 tests. The aggregate increase attributed to the three fertilizers when used separately was 443.2 pounds of seed cotton per acre, as compared with an average of 444.7 pounds increase per acre when the same ingredients were combined.

Table X shows the percentage increase in growth attributable to each ingredient when used separately, as compared with the calculated increase where it occurs in the several combinations. The results are for each of the four ingredients, lime, nitrate, potash, and phosphate, and are the averages for each of the 25 areas given in Table III. As an illustration of how the results are calculated, take the average results of the five soils from Cherokee County, S. C. Nitrate alone gave an increase of 40 per cent. Nitrate and phosphate produced an increase of 36 per cent, or 40 per cent more than phosphate alone, while nitrate and potash produced 49 per cent, or 42 per cent more than potash alone. The average effect for nitrogen in these two combinations is therefore 41 per cent and is entered in the second column under nitrogen. As NP = 36 and NK = 49, by addition (2N)PK = 85. However, PK = 3, so by difference we have 2N = 82 or N = 41, which is entered in the third column under nitrogen. NPK = 44 and since PK = 3, N in the NPK combination produced an increase of 41 per cent. The four values each for potash and phosphate and the two values for lime are obtained in the same manner. For this area the efficiency of the several ingredients is very uniform, the range of variation for nitrate, potash, and phosphate being only 1 per cent, while for lime the difference between the two observations is 7 per cent. Since the results in Table X are based upon the average of all soils from each area the variation in the efficiency of the ingredients as they occur in the various combinations is not marked. By making the same calculations for each of the soils, however, many of them show a marked variation in the efficiency of the ingredients as they occur in the several combinations, a difference far too great to be attributable to error of observation, which by actual test has been found not to exceed plus or minus 5 per cent. Where the variation in the efficiency of a fertilizer ingredient, as it occurs alone and in several combinations, exceeds the limit of error in observations as above stated, such portion of the variation as exceeds that limit must be attributable to its association with the other ingredients. Just as in a solution of several salts the presence of one may increase or decrease the solubility of others, so in the soil the addition of one ingredient may increase or decrease the effectiveness of another. It has already been shown that for quite a number of soils the effect of three ingredients combined is no better than for one of them and that one ingredient may be substituted for another with equally good effect. See Table VI, page 30. On the other hand, there are many soils in which the effect attributable to a combination of three fertilizer ingredients is two or three times greater than the aggregate effect of the same ingredients when used separately. See latter portion of Table IV, page 26.

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[a] See tabulated results on corn in "Results in Field Experiments with Various Fertilizers," by Prof. W. O. Atwater, Ph. D., U. S. Dept. Agr., 1883.

The variation in the efficiency of a fertilizer ingredient as used separately and in several combinations bears no consistent relation to the efficiency of the ingredients with which it is associated or to the efficiency of the combination as a whole. If nitrate of soda produces an increase in growth which equals or exceeds that produced when it is associated with potash and phosphate, as is frequently shown in Table IV, page 26, we would theoretically expect little or no effect from either potash or phosphate when used alone on the same soils. Contrary to this theory, however, we find that, with an occasional exception, both potash and phosphate are markedly efficient on these soils. On the other hand, if nitrate of soda produces little or no increase as compared with a fair to good increase obtained when it is combined with potash and phosphate, as is frequently shown in the latter portion of Table IV, we should expect to obtain fair to good results from potash or phosphate when used alone on the same soils. But what do we find? Usually little or no effect from potash, and a negative effect from the phosphate. Table V, page 30, which is a condensation of the results in Table IV, shows up this relationship in a striking manner. In that table is given the average percentage increase in growth attributable to each of three ingredients and their combination for groups of soils in which the aggregate effect of the ingredients differs within certain limits from that obtained when they are used in combination. It will be noticed that there is a more or less regular and parallel decline in the efficiency of each of the ingredients when used separately, from a maximum of 37, 49, and 64 per cent for phosphate, potash, and nitrate to a minimum of – 18, – 5, and 2 for the same ingredients, respectively. Notwithstanding this marked decline in the efficiency of the ingredients when used separately, the efficiency for the three ingredients combined is essentially as marked at the end of the series as at the beginning, the average effect for the first and last groups being 52 and 53 per cent, respectively. The aggregate effect of the three ingredients used separately is 150 and – 8 per cent for the same groups. (See Table V, p. 30.)

TABLE X. *Percentage increase in growth attributable to each fertilizer salt and lime, when used alone and when used in various combinations, as calculated by the difference method. Average, by areas.*

State.	Locality.	Increase with lime.		Increase with phosphoric acid.			
		L, alone.	PKNL−PKN.	P, alone.	$\frac{(PK-K)+(PN-N)}{2}$	$\frac{PK+PN-KN}{2}$	PKN−KN.
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Indiana	Newton County	−1	6	0	−6	−6	−17
Missouri	Crawford County	4	−3	6	2½	4	−4
Ohio	Westerville area	3	3	−3	4	4	−4
New York	Tompkins County	2	−9	−5	−9	−8	−5
Wisconsin	Portage County	5	−2	2	−2½	−3½	−2
New York	Binghamton area	11	−1	4	1	0	−5
Mississippi	Montgomery County	8	4	−1	−1	−4	−4
Pennsylvania	Montgomery County	5	5	5	6½	4	−5
Indiana	Tippecanoe County	2	−9	10	9½	9	3
Missouri	Scotland County	11	0	7	0	3	−4
Virginia	Hanover County	4	8	0	1	2	7
Texas	San Marcos area	14	4	8	0	8	8
Arkansas	Prairie County	26	26	5	−1½	2	−1
Mississippi	Pontotoc County	16	6	10	−3	2	6
South Carolina	York County	15	8	8	−6	−6	10
Louisiana	Caddo Parish	15	21	3	0	1	−11
Texas	Rusk County	13	7	6	−1	2	1
Tennessee	Henderson County	5	21	1	−8	−12	−8
Kentucky	McCracken County	18	6	−3	−4½	−4	0
South Carolina	Cherokee County	18	11	−4	−4	−5	−5
Alabama	Lee County	23	28	−3	−5	−4	2
Florida	Escambia County	52	35	8	−1½	4	−1
Georgia	Waycross area	32	21	2	−1	0	0
Virginia	Louisa County	38	30	30	1	4	2
North Carolina	New Hanover County	40	19	14	7	9	5

State.	Locality.	Increase with potash.				Increase with nitrogen.			
		K, alone.	$\frac{(KP-P)+(KN-N)}{2}$	$\frac{KP+KN-PN}{2}$	KPN−PN.	N, alone.	$\frac{(NP-P)+(NK-K)}{2}$	$\frac{NP+NK-PK}{2}$	NKP−KP.
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Indiana	Newton County	11	7½	10	−1	4	1½	5	−6
Missouri	Crawford County	6	1	1	−7	4	2½	6	−2
Ohio	Westerville area	5	5½	−1	−9	4	10½	10	2
New York	Tompkins County	4	2½	6	9	21	17½	18	22
Wisconsin	Portage County	3	3	6½	8	12	9½	10½	12
New York	Binghamton area	7	5	5	0	6	8	12	7
Mississippi	Montgomery County	3	5½	5	5	8	12½	13	14
Pennsylvania	do	10	14	14	5	4	6½	5	−5
Indiana	Tippecanoe County	8	4	0	−6	14	17½	21	15
Missouri	Scotland County	24	16½	18	11	14	9	13	6
Virginia	Hanover County	8	9	10	19	16	16	16	25
Texas	San Marcos area	12	1½	6	6	23	11	14	14
Arkansas	Prairie County	10	3	6	3	12	5½	9	6
Mississippi	Pontotoc County	9	−1½	6	10	28	14½	20	23
South Carolina	York County	0	0	13	30	24	21	12	28
Louisiana	Caddo Parish	13	9	9	−2	24	22½	25	14
Texas	Rusk County	11	6	11	10	32	24	26	25
Tennessee	Henderson County	1	6	16	20	36	29	28	31
Kentucky	McCracken County	3	7	13	7	39	33½	30	34
South Carolina	Cherokee County	7	8	8	8	40	41	41	41
Alabama	Lee County	6	5½	6	14	35	32½	32	39
Florida	Escambia County	19	7½	12	6	20	10	15	10
Georgia	Waycross area	15	14	16	17	45	42	42	43
Virginia	Louisa County	26	9	24	22	44	26	40	38
North Carolina	New Hanover County	21	17½	22	19	65	58½	60	57

RELATION OF FERTILIZER REQUIREMENTS TO CHARACTER OF SOILS.

That soils vary greatly in their crop-producing capacity and in the degree to which they respond to fertilizers under field conditions has long been known as a result of experience and also as a result of carefully recorded field tests. This marked difference in the degree to which various soils respond to fertilizer treatments is the most striking feature manifested in the results recorded in the preceding tables. It has also been long contended that there is a relation between the origin and the character of the soil and the character of the fertilizer that would be required to produce good results. It is doubtful, however, if such a claim can be substantiated by observed facts over a large territory. It certainly is not borne out by the results obtained on the 220 soils here reported, except in case of the muck soils which uniformly respond to potash. In fact, the character of the fertilizer

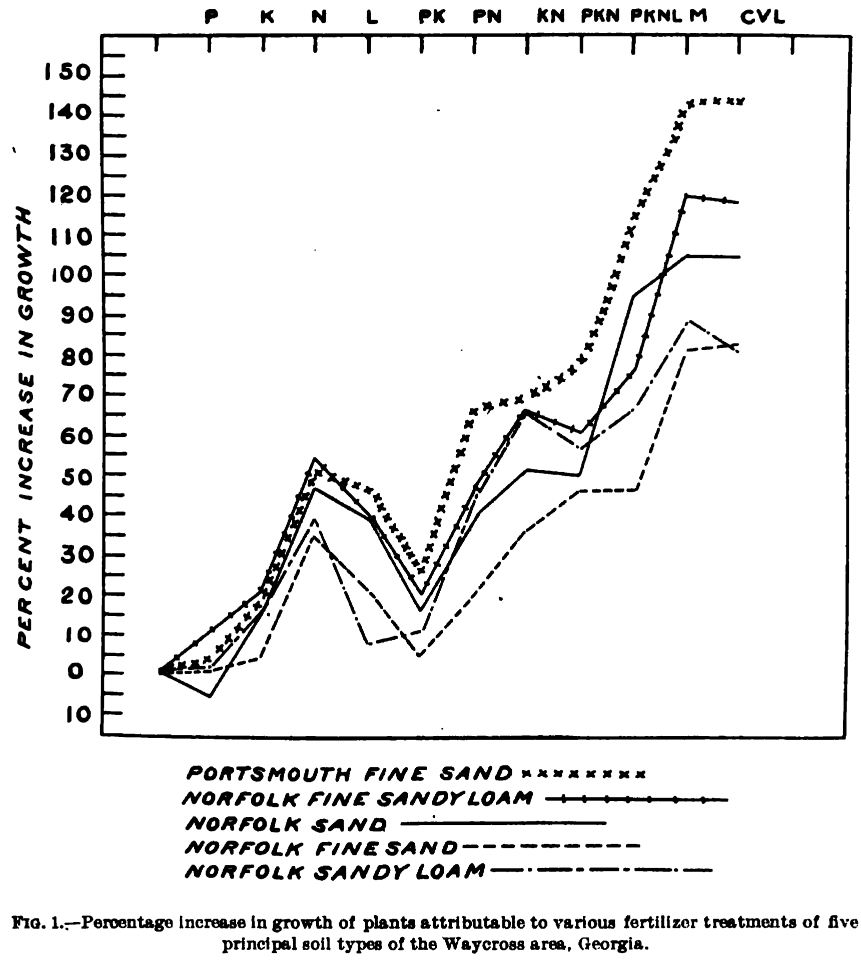


FIG. 1.—Percentage increase in growth of plants attributable to various fertilizer treatments of five principal soil types of the Waycross area, Georgia.

required for the same types or series of soils, as found in widely separated areas or localities, and as shown by these results, varies more than that required for different types and series when they occur in the same area or locality. In illustration of this point, five soils from Waycross, Ga., tested in triplicate, show a marked uniformity in the character of their manurial requirements, regardless of the fact that they represent five types and two soil series. The same soils in Escambia County, Fla., show manurial requirements of a very different character. (See Table III, p. 15, and figs. 1 and 2.)

In the Waycross area nitrate of soda is much more effective than sulphate of potash, and while lime is decidedly beneficial it is not equal to nitrate of soda. In Escambia County sulphate of potash is nearly as efficient as nitrate of soda, and lime is about twice as effective as the three fertilizer ingredients combined. These differences are based on average results for the two areas, and notwithstanding that the soils are of the same type, series, and formation, they show as marked differences in the character of fertilizer required as will be found between any of the areas, even when the soil types are entirely different.

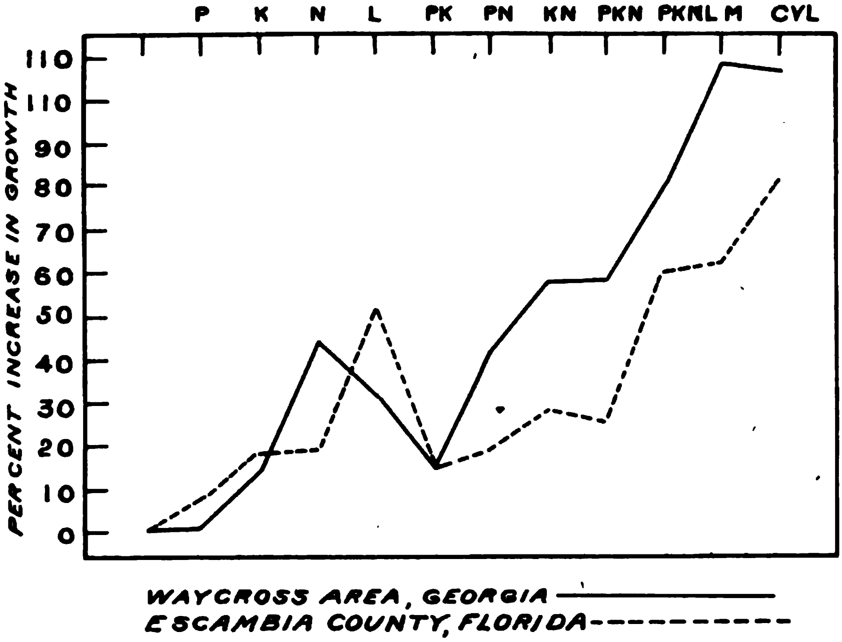


FIG. 2.—Percentage increase in growth of plants, attributable to various fertilizer treatments for soil of the Waycross area, Georgia, and Escambia County, Fla.

A Cecil sandy loam from Raleigh, N. C., was markedly improved by each of the three fertilizer salts, and also by lime, the increased growth of plants obtained when all of these ingredients were combined being 103 per cent. The same soil type from Lee County, Ala., as a result of tests on two samples, gave no response to either potash or phosphate, but produced a fair increase in growth as a result of nitrate of soda and also for lime, the maximum increase being 40 per cent where all three fertilizer salts were used in conjunction with lime. (See Table III, p. 15.)

RELATIVE EFFICIENCY OF FERTILIZERS BY LOCALITY.

In comparing the relative efficiency of the fertilizer ingredients, it is found that in the vast majority of instances nitrate of soda ranks first and lime second. This is especially true in the southern areas, where fertilizers are most extensively used. In the Central and Northern States, where the efficiency is less marked, there are quite a number of instances in which potash or phosphate outranks the lime or nitrate, although on an average the nitrate holds first rank and lime second. Sulphate of potash ranks next to lime, while acid phosphate having the lowest value, has in numerous instances shown a slightly negative effect.

With soils from the States of Wisconsin, Iowa, Missouri, Illinois, Indiana, Ohio, New York, and Pennsylvania the response to commercial fertilizers has been moderate, slight, or in many instances almost imperceptible. On those soils, also, organic manures, in the form of cowpea vines or stable manure, have been very much more effective than the chemical ones, the mean relative increase attributable to manure being nearly three times that for a complete fertilizer with lime, i. e., barnyard manure gave an average increase of 38 per cent, while the complete fertilizer with lime gave an average increase of only 13 per cent. (See Table XI, from which the averages were computed.) In these States lime alone seldom showed a marked effect. While the tests for these States are insufficient in number to represent all soil types and conditions, yet the results are in conformity with the general practices of the vast majority of farmers of these sections, who as a rule do not purchase commercial fertilizers for use in the growing of general farm crops, but who for the most part recognize the high value of barnyard manure and generally utilize all that is produced on the farm.

In the Atlantic and Gulf Coast States, including Kentucky, Tennessee, and Arkansas, for which a larger number of observations have been made and where most of the important soil types have been tested, the soils, with few exceptions, respond in a marked degree to commercial fertilizers and lime, and while cowpea vines and stable manure are on an average somewhat superior to commercial fertilizers, the differences between the relative value of these materials is small, being 54.7 and 58.6 per cent increase in growth for commercial fertilizers and manure, respectively, as compared with 13 and 38 per cent for the same materials in the former group of States. (See Table XI, from which these averages were computed.) In other words, the commercial fertilizers and lime are more than four times as effective on soils of the Altantic and Gulf Coast States as they are on those of the North Central States, including New York and Pennsylvania, while manure, when compared on the same soils, is only a half better on the soils from the former States. In this respect the results are again in conformity with the practices in the Atlantic and Gulf Coast States, where the bulk of the commercial fertilizers are used.

COMPARATIVE FERTILITY OF SOILS.

Another point brought out in the tables is the relative fertility or crop-yielding capacity of the untreated soils. Under the prevailing condition of crops and climate in the field, marked differences in this respect exist, some of the better soils showing a crop-producing capacity four or five times as great as that of the poorer ones. In these tests, where all soils are put into excellent physical condition and where moisture and temperature are always favorable, these differences are less marked but nevertheless exist to a considerable degree, as may be seen by comparing the actual weight of plants grown on the untreated soils. The average growth of plants on untreated soils from the North-Central States, including New York and Pennsylvania, is 28 per cent greater than the average of those from the Atlantic and Gulf Coast States. This difference in the initial crop-producing capacity of the soils from the two sections as indicated in the pots is sufficient to make the actual increase in growth from the stable manure nearly as great from one section as from the other.

TABLE XI.—*Increase in growth attributable to complete fertilizer with lime and manure; and proportionate cost of fertilizer to value of crops as obtained from Census, 1900.*

State.	Locality.	Weight of plants, untreated soil.	Increase from fertilizer and lime.	Increase from manure.	Cost of fertilizer to value of crop.
		Grams.	*Per cent.*	*Per cent.*	*Per cent.*
Missouri	Crawford County	9.6	0	19	0.23
Indiana	Newton County	8.8	4	56	.03
Ohio	Westerville area	7.8	8	28	.62
New York	Binghamton area	9.3	10	27	1.13
Wisconsin	Portage County	9.0	13	41	.32
Indiana	Tippecanoe County	6.8	16	37	.39
Mississippi	Montgomery County	9.3	18	18	.49
Pennsylvania	do	10.1	19	17	3.28
New York	Tompkins County	7.9	10	46	1.98
Missouri	Scotland County	9.6	28	69	.08
Texas	San Marcos area	8.5	32	26	.04
Mississippi	Pontotoc County	6.8	38	24	.03
Arkansas	Prairie County	8.3	40	21	.72
Virginia	Hanover County	7.5	41	38	4.04
South Carolina	York County	6.2	43	72	6.34
Louisiana	Caddo Parish	6.3	45	54	.21
Texas	Rusk County	8.0	45	67	.29
Kentucky	McCracken County	5.0	48	70	.22
South Carolina	Cherokee County	7.2	55	64	5.54
Tennessee	Henderson County	7.5	57	72	.10
Florida	Escambia County	6.3	61	63	6.82
Alabama	Lee County	6.4	70	65	4.81
Georgia	Waycross area	6.0	80	108	4.45
Virginia	Louisa County	5.9	96	44	4.50
North Carolina	New Hanover County	5.2	107	131	7.82

RELATIVE RESPONSE TO FERTILIZERS AND EXPENDITURES FOR FERTILIZERS.

In Table XI, where the average percentage increase in growth attributable to the complete fertilizer and lime is given for each area and arranged in an ascending series, there is also given the average percentage increase attributable to stable manure for the same soils as well as the expenditure for commercial fertilizers for the same areas or counties. The expenditure for fertilizers in the area is expressed in percentage of the valuation of products other than those fed to live stock and is computed from statistics reported in the United States Census for the year 1900.

This table, besides showing the relative response to the chemical fertilizer and stable manure, which was discussed in preceding pages, also brings out the relation between the response to a complete fertilizer and lime, as obtained by the paraffin pot test, and the expenditure for fertilizer in each county or area expressed in percentage of the valuation of crops produced.

The table is separated into two portions, the first portion embracing 13 areas or counties in which the increase in growth attributed to a complete fertilizer and lime ranges from 0 to 40 per cent, and the second portion embracing 12 areas or counties in which the increased growth for the same treatment ranges from 41 to 107 per cent. In the first portion of the table there are no localities where the valuation of commercial fertilizer used equals 4 per cent of the value of the products grown, while in the second portion there are only four localities where it does not exceed such percentage. In the first portion of the table where the response to the fertilizer with lime does not exceed 40 per cent there are only three localities where the cost of fertilizer actually used in 1900 exceeded 1 per cent of the valuation of the crop grown. These exceptions are in New York and Pennsylvania, in areas where special crops probably receive more attention than in the others. The one in Pennsylvania was immediately about Philadelphia. Their nearness to both the great produce and fertilizer markets is also a factor tending to the more extensive use of fertilizers.

Of the four counties in the second portion of the table in which the cost of fertilizers used does not exceed 4 per cent of the value of crops grown, McCracken County, Ky., and Henderson County, Tenn., are each represented by only one sample. If better represented, they would probably fall in the first portion of the table, as indicated by the small amount of fertilizer used. The remaining two counties are Caddo Parish, La., and Rusk County, Tex., in each of which cases but little commercial fertilizer is used, though they are grouped in the second portion of the table as a result of their response to fertilizers in the pot test. In these two counties the soils were well represented by the samples tested, and the results indicate that the moderate use of commercial fertilizer might prove profitable. There are other factors, however, besides the comparative response to fertilizers which are concerned in their profitable use. Low value of land, long distance from markets and seat of supplies, including fertilizer, would all tend

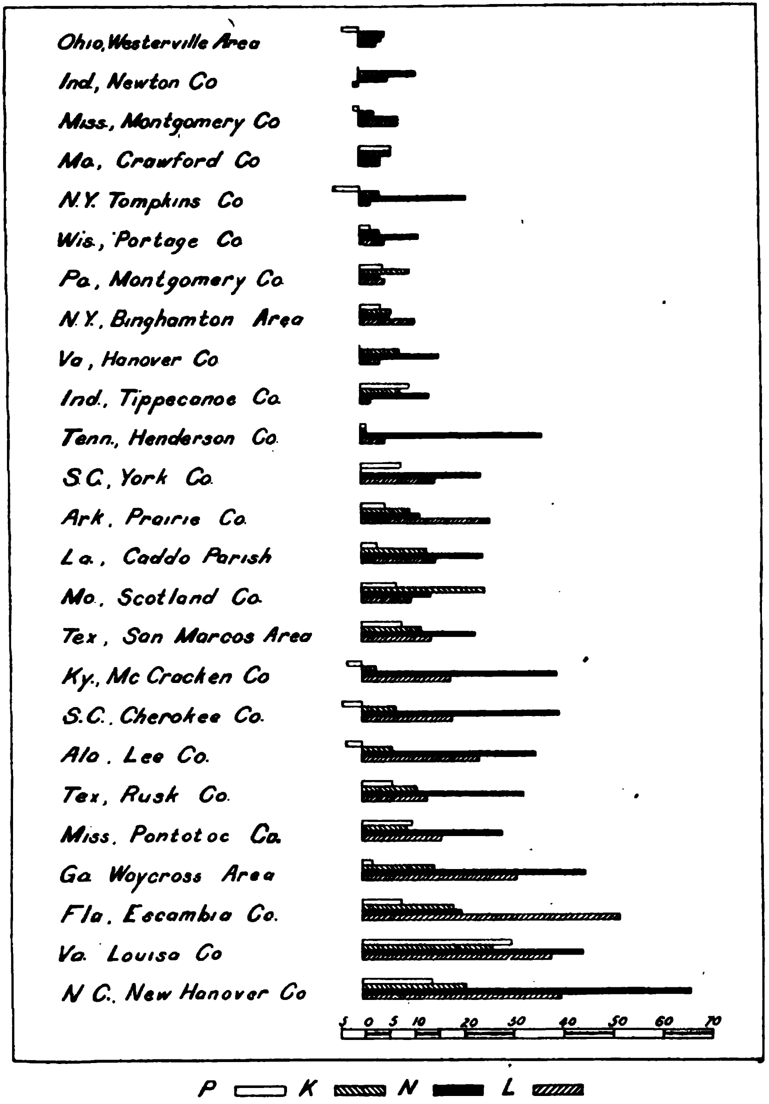


FIG. 3.—Percentage gain in plant growth attributable to each of the salts P, K, N, and L when used alone.

toward the unprofitable use of fertilizers. In Rusk County, Tex., and Caddo Parish, La., a few farmers have begun the use of commercial fertilizers and find them profitable.

AVERAGE EFFICIENCY OF FERTILIZER SALTS, BY LOCALITY.

Figure 3 shows graphically the percentage increase in growth attributable to each of the fertilizer salts and lime when used separately, and is based on the average for all soils of each area as given in Table X on page 43. The areas are arranged in an ascending series according to the aggregate increase from all ingredients, which ranges from a minimum of only 9 per cent for the Westerville area, Ohio, to a maximum of 140 per cent for New Hanover County, N. C. The range in the efficiency of the individual salts is also marked, the increase attributable to nitrate of soda varying from 4 per cent in several of the areas in the upper part of the diagram to 65 per cent in New Hanover County, N. C., and that for lime varying from a slightly negative result for Newton County, Ind., to an increase of 52 per cent for Escambia County, Fla., with somewhat lesser variations for potash and phosphorus. In the majority of the areas the efficiency of the three fertilizer ingredients and lime assume the same order. In 16 of the 25 areas, nitrate of soda was the dominant salt, while lime was dominant in 3 and potash in 3 of the areas. In 14 areas out of 25 lime ranks second in efficiency. In the States of Indiana, Missouri, Pennsylvania, and Virginia potash seems to have been relatively more effective than elsewhere. In the Arkansas and Florida areas lime is largely responsible for their position in the series, and in both of them nitrate of soda holds a relatively low rank.

TABLE XII.—*Average percentage increase in growth for all fertilizers and combinations, by soil series.*

Soil series.	No. of soils.	Weight of plants grown on untreated soil.	Increase in growth attributable to—										
			P.	K.	N.	PK.	PN.	KN.	PKN.		PKNL.	M.	CvL.
		Grams.	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*
Portsmouth	7	5.2	10	19	43	25	53	63	68	43	96	100	117
Norfolk	45	6.3	6	16	35	16	34	47	45	28	64	76	83
Cecil	12	6.0	14	12	36	17	32	46	52	26	69	62	65
Orangeburg	18	8.0	2	4	20	8	23	23	31	11	37	42	44
Miami	8	7.9	5	9	11	4	15	18	19	4	19	44	17
Marshall	5	7.0	5	8	16	6	10	20	12	4	8	50	8
Muck	4	6.0	21	62	27	56	33	49	60	30	60	46	39

TABLE XIII.—*Percentage increase in growth attributable to each fertilizer salt and to lime when used alone, as compared with its calculated effect when used in various combinations. Averages for each of six series and Muck.*

Soil series.	L.		P.				K.				N.			
	L, alone.	PKNL−PKN.	P, alone.	$\frac{(PK-K)+(PN-N)}{2}$	$\frac{PK+PN-KN}{2}$	PKN−KN.	K, alone.	$\frac{(KP-P)+(KN-N)}{2}$	$\frac{KP+KN-PN}{2}$	KPN−PN.	N, alone.	$\frac{(NK-K)+(NP-P)}{2}$	$\frac{NK+NP-KP}{2}$	NPK−PK.
Portsmouth..	43	28	10	8	7½	5	19	17½	17½	15	43	43½	45½	43
Norfolk......	28	19	6	−½	1½	−2	16	11	14½	11	35	29½	32½	29
Cecil..........	26	17	14	½	1½	6	12	6½	15½	20	36	26	30½	35
Orangeburg..	11	6	2	3½	4	8	4	4½	4	8	20	20	19	23
Miami........	4	0	5	−½	½	1	9	3	3½	4	11	9½	14½	15
Marshall.....	4	−4	5	−4	−2	−8	8	2½	8	2	16	8½	12	6
Muck.........	30	0	21	0	20	11	62	28½	36	27	27	−½	13	4

COMPARATIVE EFFICIENCY OF FERTILIZERS, BY SOIL SERIES.

Table XII gives the average percentage increase in growth attributable to each fertilizer salt and combination of salts, by soil series, using only those in which the treatments were uniform and complete. No series were used where less than 5 samples were available, except in the case of Muck, in which only 4 samples were used.

Table XIII gives the percentage increase in growth attributable to each of the three fertilizer ingredients and lime, as compared with their effect when used in the combinations, the efficiency in the combinations being calculated by the difference method previously explained. These two tables show that the relative efficiency of the three salts and lime is essentially the same for all the soil series except the Muck. The range of efficiency of the complete fertilizer with lime is very marked, varying from a maximum of 96 per cent for the Portsmouth series to only 8 per cent for the Marshall series. It is noticeable that barnyard manure is relatively much more efficient for the Marshall and Miami series than for the others.

Figure 4 shows graphically the average relative percentage effectiveness of the three fertilizer ingredients and lime by series when used separately, as given in Table XIII. The variation in the aggregate effectiveness of the three salts and lime for the several series is nearly as great as when the soils were grouped by localities. It is evident, however, that the serial grouping is, to some extent, a locality grouping also, the Marshall and Miami series, which are the least responsive to the commercial fertilizers, occurring only in those States in which fertilizers are but little used, while the Portsmouth and Norfolk series are confined wholly to the Atlantic seaboard, where fertilizers are most extensively used. While there is a marked difference in the aggregate effectiveness of the three salts and lime on different series, ranging from a minimum of 29 per cent for the Miami series to a maximum of 115 per cent for the Portsmouth series, broadly speaking the relation between the value of the individual ingredients in the several series is remarkably uniform, even more so than occurs when the soils are considered by areas. The Muck, represented by only 4 samples, is exceptional, and shows the characteristic importance of potash, that ingredient being on the average about as effective as the total of lime, nitrogen, and phosphate. This fact is also in conformity with our field knowledge of Muck and Peat, which are greatly benefited by applications of potash salts.

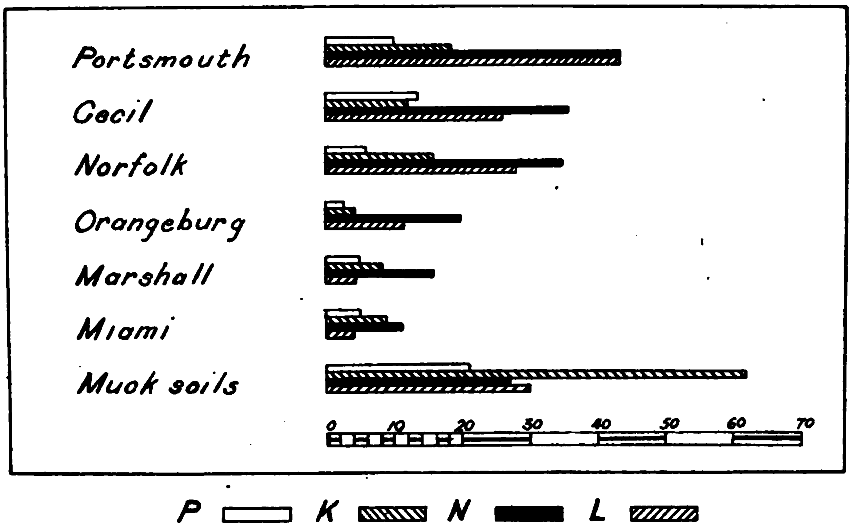


FIG. 4.—Relative efficiency of fertilizer ingredients by soil series, when the ingredients are used alone.

TABLE XIV.—*Average percentage increase in growth attributable to each fertilizer salt and lime for soils of the Norfolk, Portsmouth, Orangeburg, and Cecil series when classified by texture.*

Soil class.	Number of soils.	L.		P.				K.				N.			
		L, alone.	PKNL–PKN.	P, alone.	$\frac{(PK-K)+(PN-N)}{2}$	$\frac{PK+PN-KN}{2}$	PKN–KN	K, alone.	$\frac{(KP-P)+(KN-N)}{2}$	$\frac{KP+KN-PN}{2}$	KPN–NP.	N, alone.	$\frac{(NP-P)+(NK-K)}{2}$	$\frac{NP+NK-KP}{2}$	NKP–KP.
Coarse sand	2	14	9	−10	−10	−4	7	8	5	8	19	34	26	24	35
Sand	12	43	33	7	−1.5	2	−1	16	10	16	13	42	32.5	35	32
Fine sand	17	33	21	5	2.5	3	3	15	13.5	15	15	37	35	36	36
Sandy loam	17	14	11	6	0	0	4	9	7	11	15	27	24	27	31
Fine sandy loam	25	22	13	8	3	5	0	13	8.5	10	6	27	23.5	26	22

EFFICIENCY OF FERTILIZER AS RELATED TO SOIL TEXTURE.

Table XIV gives the response to each of the three salts and lime when used alone and when in the various combinations for soils of the Norfolk, Portsmouth, Cecil, and Orangeburg series when grouped by the variation in texture. This grouping of the soil fails to bring out any variations in the character of the fertilizer required for the different textures, but it does show in general that the finer the texture of the soil, the less marked is the effect of the various fertilizer salts or the aggregate effect of them all.

NATURAL FERTILITY AS RELATED TO RESPONSIVENESS TO FERTILIZERS.

Another comparison brought out in the general tables is the relation between the crop-producing capacity of the untreated soils in the pots and their response to fertilizers. In general, the lower the crop capacity, the greater the response to fertilizers or manure, and vice versa.

Table XV shows the average effectiveness of a complete fertilizer and lime on soils arranged in groups according to the weight of plants grown when untreated, and it is shown that there is a gradual and consistent decrease in the effect of the treatment, as the untreated soils are capable of producing larger plants.

TABLE XV.—*Showing decreasing effect of fertilizers with increasing productiveness in untreated samples.*

Number of soils.	Weight of plants on untreated soil.	Average gain attributable to fertilizers.
	Grams.	*Per cent.*
23	3 to 4.9	87.9
35	5 to 5.9	68.3
25	6 to 6.9	41.8
46	7 to 7.9	40.1
33	8 to 8.9	23.9
19	9 to 9.9	26.8
9	10 to 10.9	13.0
9	11 to 11.9	8.4
7	12 and over	3.9

It is significant that the sandy soils of the Norfolk and Portsmouth series, collected from the Southern States where wheat is seldom grown, have produced on an average larger and more thrifty wheat plants by the application of a complete fertilizer and lime, than have been produced by the same or other treatments on soils of the Marshall or Miami series from Wisconsin, Ohio, Indiana, and New York, where wheat does well. This fact is in harmony with the view now gaining prevalence, that the variation in the character and composition of the mineral matter of soils is of minor importance as regards crop adaptation and yielding capacity, except so far as character of material influences condition of the soil in its relation to soil moisture and permeability to air, water, and the roots of plants. In other words, crop adaptation and crop-producing power depend more upon climatic environment and physical condition of the soil than upon soil type or the geological formation from which it is derived. The best wheat soils or those best suited to peaches or to truck crops are not so solely by virtue of the character of the mineral matter of which they are composed, but because there are present climatic and soil conditions that enable those classes of plants to attain perfection.

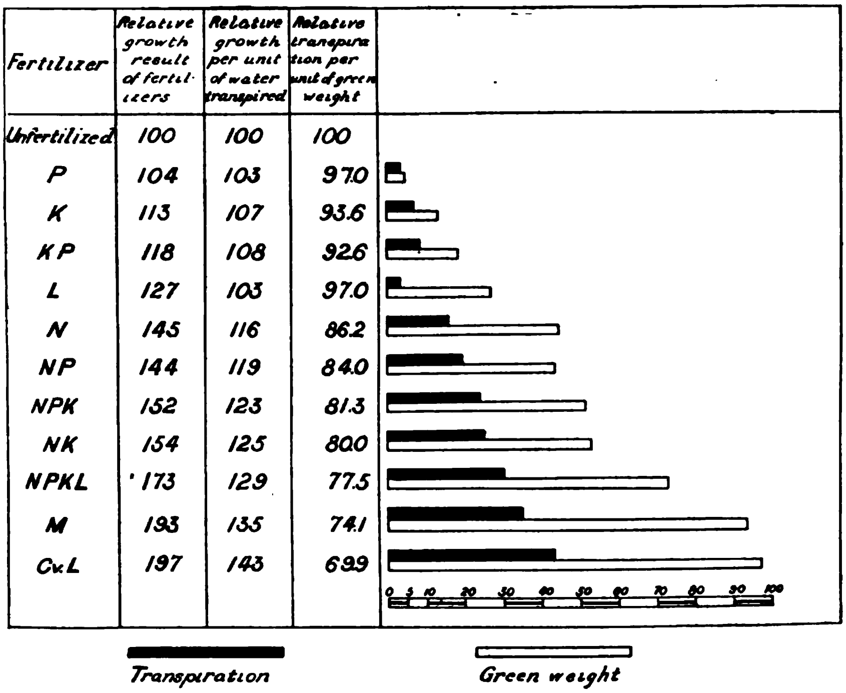
The poorest soils, by proper manipulation and the addition of suitable manure or fertilizer, can be made to produce as large yields in the pots as can be procured by the same or other treatments on the best soils that occur, and yet such applications have but slightly altered the composition of the soil. Such improvement does not involve any considerable length of time, but may be brought about in a few days or at most a few weeks. This does not mean that it would be either feasible or practical to attempt such a radical change under field conditions in so short a time. The expense involved would not justify the procedure, neither would the soil be able to maintain such an ideal condition under the adverse climatic conditions which might prevail or against the poor systems of farming in vogue. The improvement of soil conditions in the field becomes a purely business proposition in which the expense involved must not exceed probable returns.

Important in this connection is the assembling and association of all those factors that will work together for the good of the soil, such as the selection of suitable crops, the use of a proper rotation, the adoption of catch and winter cover crops, and cultivation of such character that erosion will be reduced to a minimum and the rainfall absorbed and retained in ample supply. By such procedure the condition of a soil will in time become greatly modified and its fertility improved. So-called soil robbery is, after all, more properly soil mutilation, brought about by the carelessness of man.

FERTILIZERS AND ECONOMY OF WATER IN PLANT GROWTH.

It has been stated that no attempt will be made to explain how fertilizers effect an increase in plant growth, yet there is one point which has been established as a result of this investigation of which mention should be made. It is the relation between growth, as effected by fertilizers, and water transpired by the plants or used in the process of their growth. In all of the tests a careful record has been kept of the water transpired for each of the 13,000 or more pots. As a result of such observations, it has been found that as fertilizers increase plant growth, there is a marked diminution in the water transpired per unit of growth; or, putting it in the reverse order, there is a marked increase in growth for a unit of water used, and such increase becomes greater as the fertilizers are more effective. As a result of computations for twenty soils taken at random, it was found that the percentage increase in growth for a unit of water used equaled, approximately, one-half of the total increase in growth resulting from the fertilizer treatments.

Figure 5 gives the average results for 20 soils and shows not only the gain in growth following the fertilizer treatments, but also shows the associated increase in growth per unit of water transpired.



Fertilizer	Relative growth result of fertilizers	Relative growth per unit of water transpired	Relative transpiration per unit of green weight
Unfertilized	100	100	100
P	104	103	97.0
K	113	107	93.6
KP	118	108	92.6
L	127	103	97.0
N	145	116	86.2
NP	144	119	84.0
NPK	152	123	81.3
NK	154	125	80.0
NPKL	173	129	77.5
M	193	135	74.1
Cv.L	197	143	69.9

FIG. 5.—Percentage increase in growth of plants attributable to fertilizer and accompanying increase per unit of water transpired. Average of 20 soils.

Excepting lime, in the presence of which transpiration remains nearly normal, the different fertilizer constituents show no marked variation in respect to this phenomenon. Lime frequently produces an increase in growth and yet the plants maintain practically the same rate of transpiration per unit of growth as that observed for the untreated soil.

In a few miscellaneous tests, where the different forms of potash were tried, it was found that kainit and muriate of potash decreased the rate of transpiration per unit of growth, as compared with sulphate of potash.

While these observations have no economic significance in the pots where moisture content is always ample, they may be of considerable importance in relation to the use of fertilizers in the field and explain, in part, the benefits derived therefrom. It frequently happens, owing to scanty rainfall, or a low water-holding capacity of the soil, that the available water supply is the limiting factor in crop yields. Where such conditions exist, and they occur frequently in all parts of the country, the presence of a fertilizer which would enable the crop to economize in its water consumption would be of considerable importance and might, as pointed out above, enable the crop to make a marked increase in growth despite the limited water supply.

SUMMARY.

The paraffin-pot method of testing the manurial requirements of soils, used in these investigations, while not designed to supersede field tests, is admirably adapted to an investigation of this kind and is very useful as a method of indicating what fertilizers should be used in the field.

The results obtained in the pots with the various ingredients are relatively the same as those obtained in the field, but may differ in degree. This is true of all ingredients commonly used except the phosphates, which give a relatively lower effect in the pots than the others. The absolute effect is usually greater in the field than in the pots and phosphates may frequently be economically used where their benefits are not indicated by the pots.

The results obtained in the pots generally agree with the fertilizer practices in the various sections from which the soils were secured. In the North Central States, where but little commercial fertilizer is used, and where the main dependence is placed upon barnyard manure, the pot tests show manure to be three times as efficient as the fertilizer. In the Atlantic seaboard and Gulf Coast States, where but little manure is available, and where the main dependence is upon commercial fertilizers, the manure as tested in the pots has been only slightly superior to the fertilizers. Muck, quite generally recognized as in need of potash in the field, has shown that ingredient to be nearly as efficient as lime, nitrate, and phosphate combined, as determined by the pot tests.

Transpiration, while a good indicator of the relative growth of plants when under like conditions, usually gives a range of lesser magnitude than the variation by green weights.

The green weight of plants grown for about twenty-five days in the pots occasionally equals or exceeds 1 per cent of the weight of the soil in which they grew. Such plants contain about 85 per cent of water and transpire approximately 100 grams of water for each gram of green matter produced. The dry matter of such plants is richer in mineral constituents and nitrogen than that of the same plants if matured. The draft on the water and mineral constituents of the soil under these conditions is greater than that occasioned by the removal of a large and matured crop under field conditions.

As an average of all tests, the organic manures have outranked the chemical ones. Barnyard manure and cowpea vines with lime tie for first rank. The three chemical salts with lime rank third and the same salts without lime rank fourth.

Of the combinations of chemical salts the order of efficiency is as follows: The three salts with lime, first; three salts alone, second; potash and nitrate, third; phosphate and nitrate, fourth, and phosphate and potash, fifth.

Of the salts used individually the order is nitrate, lime, potash, and phosphate; nitrate being the most efficient and phosphate the least efficient.

As an average result of all tests, nitrate of soda has produced a marked increase in growth which has not been further increased by the addition of acid phosphate. Potash has produced a moderate increase in growth and when supplemented by nitrate the effect has been slightly less than the aggregate of these two ingredients when used separately. The efficiency of the combination of nitrate and potash has not been appreciably improved by the addition of phosphate..

Lime alone has generally produced a marked increase in growth and has usually increased the efficiency of a complete fertilizer. There is but little evidence that the benefits derived from lime are due to beneficial action on nitrification.

Soils vary greatly in crop-producing capacity as found under field conditions. Part of such variation is due to physical condition and consequent relation to water, and is largely overcome in the pots. After these conditions are largely equalized in the pots marked differences in crop-yielding capacity still exist to such an extent that good soils may produce four or five times as large a growth as that produced on very poor soils under the same conditions. By the application of suitable manures or fertilizers these differences are overcome, and in the pots the poorest soils when treated with suitable substances become as productive as the best ones.

Soils vary greatly in the degree to which they respond to commercial fertilizers, lime, manure, and green manure. In general, the degree of response varies inversely as the crop-yielding capacity and ranges from zero to several hundred per cent. The soils of the Atlantic and Gulf Coast States are much more responsive than those of the Central and Northern States.

In 60 per cent of the soils here tested, each fertilizer salt appears to have a special function, so far as it influences the growth of plants, which is not materially modified by the addition or withholding of the other salts. In 29 per cent of the soils the functions of the several salts, as affecting the growth of plants, are more or less interchangeable, there being quite a number of instances when each salt used alone gave as large an increase in growth as was secured by combining three of them. In 11 per cent of the soils each salt not only has a distinct function, but it is dependent upon the presence of others for its fullest effect as shown by a much greater efficiency when used in combination than when used alone. There is no apparent relation either by soil type or by locality to this grouping of the soils.

The variation in the efficiency of a fertilizer salt as used alone and in combination with various other salts bears no consistent relation to the efficiency of the associated salts or to the efficiency of the combination as a whole.

In the pots, as an average of all tests, the aggregate efficiency of the several salts when used separately is slightly greater than when the same salts are used in combination. Under field conditions, as an average of many tests, the aggregate of individuals is the same as when used in combination. Individual soils show wide variation in respect to this point.

The character of fertilizer indicated for a specific soil type as it occurs in widely separated localities usually varies more than that for very different types when in the same locality and subjected to similar environment.

The character of fertilizer indicated for various soil series is essentially the same, although the response to such a fertilizer varies greatly.

In general, the finer the texture of soils the less responsive are they to fertilizers, although the character of fertilizer indicated remains the same.

With few exceptions the character of fertilizer required for soils depends more upon local conditions and practices than it does upon the type of soil or the geological formation to which it belongs. The Muck soils are an exception and show a universal response to potash salts.

The condition of the soil is of greater importance than its chemical composition.

Without materially changing the composition of the soil, poor soils by proper manipulation and suitable applications can be made to produce as large crops in the pots as can be grown on the best soils by the same or other treatments.

Fertilizers when effective aid plants to economize in the use of water.

In conclusion it may be said that the crop-yielding capacity of soils is increased by improving their physical condition and by supplying manures or fertilizers. Frequently both are necessary, and the latter may assist the former. By the employment of both methods poor soils may become as productive as the best ones. There is but little to indicate any relation between the formation and character of the soil and character of fertilizer to which it will respond. Usually soils of a limited locality, where climatic condition and farm practices are uniform, show but little difference in the character of fertilizer required, although the degree of response may vary greatly for different fields, making their use profitable in some instances and unprofitable in others. Except in the most general way, the fertilizer requirement of soils becomes a problem for each farm or for each class of farms under like conditions of soil, climate, and system of cropping and fertilization. The indications are that fertilizers containing relatively more potash and nitrogen than do those now in general use would prove more effective. This conclusion (to which exception might be taken by some because of the fact that phosphates are known to be economically used on some soils that fail to respond to that salt in the pots) is not based alone on the result of this investigation, but upon the tendency of the more progressive planters to use a higher grade fertilizer, i. e., one containing relatively more nitrogen and potash than that used in the past. Lime has proved quite generally beneficial, being on an average more effective than both potash and phosphate.

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Issued November 2, 1907.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS—BULLETIN No. 49.
MILTON WHITNEY, Chief.

THE ACTION OF WATER AND AQUEOUS SOLUTIONS UPON SOIL CARBONATES.

BY

FRANK K. CAMERON AND JAMES M. BELL.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1907.

LETTER OF TRANSMITTAL.

United States Department of Agriculture,
Bureau of Soils,
Washington, D. C., July 20, 1907.

Sir: I transmit herewith a technical paper by Frank K. Cameron and James M. Bell, entitled The Action of Water and Aqueous Solutions upon Soil Carbonates, which I recommend to be published as Bulletin No. 49 of this Bureau. The manuscript has been gone over with Assistant Secretary Hays, who authorizes me to state that he concurs in my recommendation for its publication.

Very respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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THE ACTION OF WATER AND AQUEOUS SOLUTIONS UPON SOIL CARBONATES.

INTRODUCTION.

Lime as a mineral constituent of soil amendments or fertilizers has always occupied a prominent place in soil chemistry. It is usually applied to the soil as a sulphate (gypsum or land plaster), phosphate, hydrate (or oxide), or carbonate. The solubility of these substances is obviously of the utmost importance in determining their distribution and effectiveness when applied to the soil. Nevertheless, the literature regarding their solubilities has been most confusing and contradictory, and in consequence agricultural investigations have suffered seriously in that observations have been interpreted in the light of uncertain or conflicting premises. In many cases, indubitably, the truth has been missed on this account and conclusions deduced which have not only delayed or misguided scientific investigation, but have led to serious disappointment when brought under the test of actual farm practice. For these reasons the investigation of the fundamental solubility data and the chemical relations between the lime salts and aqueous solutions has been deemed necessary in the studies which this Bureau is prosecuting on soils and fertilizers.

The present state of our knowledge as regards the solubility of the sulphate[a] and the phosphates[b] of calcium has been shown in recent publications of the Bureau. The present bulletin contains similar data for the hydrates and carbonates of lime; and since magnesia and its compounds are so closely related to lime and its corresponding compounds, both in chemical properties and mineral associations, data for the hydrates and carbonates of magnesia are also included. In searching the literature for the material contained in this bulletin an enormous number of papers was found, especially with regard to the solubility of lime carbonates. Many of these, however, it has not been deemed wise to cite—when they had only a local or fugitive interest, when they were of a qualitative nature only, when they would add but further and unnecessary confirmation to points brought out by other data cited, or when, as occasionally happened, they were obviously trivial or of doubtful accuracy. It is believed, however, that the data given will furnish an approximately complete statement of our present knowledge of the subject. It is also believed that this material will have an interest for geologists and certain technical manufacturers second only to that for agriculturists.

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[a] Bul. No. 33, Bureau of Soils, U. S. Dept. Agr. (1906).

[b] Bul. No. 41, Bureau of Soils, U. S. Dept. Agr. (1907).

One of the great agricultural problems of the United States is the alkali, or accumulation of soluble salts frequently found in the soils of the arid areas of some of the Western States, and to a proper understanding and satisfactory handling of this important practical problem, a knowledge of the chemistry of the solutions formed by the action of water on the mineral components of these soils is of fundamental importance. The chemistry of "white alkali" has been treated quite fully in previous publications of this Bureau and especially the important reactions between gypsum and solutions of the more soluble salts found in the soil. The present bulletin brings together our knowledge of the reactions between the same solutions and calcium carbonate, the immediate source of the much-dreaded "black alkali." An intelligent interpretation can now be made of the analyses of drainage waters and the changes in the soil which they indicate. A scientific foundation is now prepared for the further development of practical methods for handling this important agricultural problem.

CARBON DIOXIDE.

SOLUBILITY OF CARBON DIOXIDE IN WATER.

The solubility in water of carbon dioxide, like all other gases, is greater at the lower temperatures than at the higher temperatures. With one or possibly two known exceptions, the solubility in aqueous solutions is decreased by increasing quantities of the material in solution. Thus, the solubility of carbon dioxide in water is decreased either by increasing the temperature or by the addition of some material, such as sodium chloride or other salts. The results of the work recorded in the literature have been assembled and are given in the following tables. The results are given in the same form as they have been recorded in the original papers. For instance, the solubility of carbon dioxide in water at 10° C. has been given by Bunsen as 1.1847. This means that one cubic centimeter of water at 10° will dissolve the quantity of carbon dioxide occupying 1.1847 cubic centimeters at 0° and 760 mm. *All the gaseous volumes are reduced to 0° and 760 mm. pressure.* In this way comparisons may be made between the solubility of the gas in solvents at different temperatures and also in different solutions.

TABLE I.—*Solubility of carbon dioxide in water at different temperatures.*

Temperature.	Bunsen.[a]	Setschenow.[b]	v. Wroblewski.[c]	Bellati and Lussana.[d]	Bohr and Beck.[e]	Prytz and Holst.[f]	Bohr.[g]	Geffcken.[h]
° C.								
0	1.7967		1.797			1.7308	1.713	
1	1.7207						1.646	
2	1.6481						1.548	
3	1.5787						1.527	
4	1.5126						1.473	
5	1.4497						1.424	
6	1.3901						1.377	
7	1.3339						1.331	
8	1.2809						1.282	
9	1.2311						1.237	
10	1.1847						1.194	
10.75				1.1281				
11	1.1416						1.154	
12	1.1018						1.117	
12.43			1.086					
12.68				1.0414				
13	1.0653						1.083	
14	1.0321						1.050	
15	1.0020						1.019	1.070
15.2		1.0090						
16	.9753						.985	
17	.9519						.956	
17.1		.9619						
17.6		.932						
18	.9318						.928	
18.38		.896						
19	.9150						.902	
19.3		.885						
20	.9014						.878	
21		.838					.854	
21.7		.825						
22							.829	
22.17				.8375				
22.4	.8642							
23		.798					.804	
24							.781	
25							.759	.8255
26							.738	
27							.718	
28							.699	
29							.682	
30							.665	
35							.592	
37.29					0.5629			
40							.530	
45							.479	
50							.436	
55							.394	
60							.359	
100					.2438			

[a] Ann. Chem. Pharm., **93**, 1 (1855); Phil. Mag. (4), **9**, 116, 181 (1855).

[b] Arch. gesammt. Physiol., 8, 1 (1874); Mémoires de l'acad. impér. des sci. de St.-Pétersb. (7), **22**, No. 6 (1875); **34**, No. 3 (1886); **35**, No. 7 (1887); Ann. Chim. Phys. (6), **25**, 226 (1892).

[c] Ann. Phys. Chem., **254**, 290 (1883).

[d] Atti Ist. Veneto (6), **7** (1889); abstr. in Beibl. Ann. Phys. Chem., **14**, 18 (1890).

[e] Ann. Phys. Chem., **280**, 318 (1891).

[f] Ann. Phys. Chem., **290**, 130 (1895).

[g] Ann. Phys. Chem., **304**, 500 (1899).

[h] Zeit. phys. Chem., **49**, 257 (1904).

TABLE II.—*Solubility of carbon dioxide in water under different pressures.*[a]

Pressure.	Solubility at—	
	0° C.	12.43° C.
Atmospheres.		
1	1.797	1.086
5	8.65	5.15
10	16.03	9.65
15	21.95	13.63
20	26.65	17.11
25	30.55	20.31
30	33.74	23.25

[a] v. Wroblewski, Ann. Phys. Chem., **254**, 290 (1883).

It will be seen that at the higher pressures the solubility of carbon dioxide in water is not proportional to the pressure as would be expected from Henry's law. At the lower pressures, below 5 atmospheres, the solubility is almost proportional to the pressure.

SOLUBILITY OF CARBON DIOXIDE IN AQUEOUS SOLUTIONS.

Sulphuric acid.

TABLE III.—*Solubility of carbon dioxide in aqueous solutions of sulphuric acid.*[a]

H_2SO_4 per liter.	Solubility at—	
	15° C.	25° C.
Grams.		
25.1	1.016	0.7923
25.3	1.016	.7936
47.8	.9772	.7693
50.9	.9775	.7685
52.3	.9756	.7672
95.8	.9175	.7302
102.3	.9143	.7273
185.7	.8354	.6736
186.2	.8385	.6747

[a] Geffcken, Zeit. phys. Chem., 49. 257 (1904).

TABLE IV.—*Solubility of carbon dioxide in various mixtures of sulphuric acid and water at 17° C.*[a]

H_2SO_4 in solution.	Solubility.	H_2SO_4 in solution.	Solubility.
Per cent.		*Per cent.*	
100.0	0.932	84.5	0.660
96.8	.852	73.1	.705
92.0	.719	8.58	.857

[a] Setschenow, Mélanges phys. et chim. du bul. de l'acad. impér. des sci. de St.-Pétersb., 9, 617 (1876), Ann Chim. Phys. (6). 25, 226 (1892).

Tables III and IV show that in the comparatively weak solutions of sulphuric acid the solubility of carbon dioxide is decreased by increasing that concentration. On the other hand, starting from sulphuric acid (100 per cent H_2SO_4) the solubility of carbon dioxide is decreased by the addition of water, in which the solubility of the gas is less than in either sulphuric acid or pure water.

Nitric acid.

TABLE V.—*Solubility of carbon dioxide in aqueous solutions of nitric acid.*[a]

HNO_3 per liter.	Solubility at—	
	15° C.	25° C.
Grams.		
29.7	1.073	0.8382
29.9	1.075	.8366
35.1	1.069	.8387
44.4	1.080	.8447
87.1	1.093	.8620
87.4	1.093	.8622
117.2	1.105	.8752
158.7	1.109	.8839
160.0	1.111	.8865

[a] Geffcken, Zeit. phys. Chem., 49, 257 (1904).

Nitric acid solutions form the striking exception to the generality that the solubility of carbon dioxide is decreased by the addition of some other solute. It will be seen from Table V that the solubility of carbon dioxide is increased by adding nitric acid to the solution.

Hydrochloric acid.

TABLE VI.—*Solubility of carbon dioxide in aqueous solutions of hydrochloric acid.* [a]

HCl per liter.	Solubility at—	
	15° C.	25° C.
Grams.		
18.2	1.041	0.8047
18.7	1.042	.8074
44.2	1.020	.7973
45.6	1.023	.7984
75.9	0.9864	.7951
79.6	1.009	.7951

[a] Geffcken, Zeit. phys. Chem., 49, 257 (1904).

Citric acid.

TABLE VII.—*Solubility of carbon dioxide in aqueous solutions of citric acid at 15.2°.* [a]

Citric acid per liter.	Solubility.	Citric acid per liter.	Solubility.
Grams.		*Grams.*	
12	1.007	198	0.893
49	.975	298	.841
99	.950	595	.719

[a] Setschenow, Ann. Chim. Phys. (6), 25, 226 (1892).

Sodium chloride.

TABLE VIII.—*Solubility of carbon dioxide in aqueous solutions of sodium chloride at different temperatures.*

Temperature.	6.52 [a] per cent solution.	7.062 [b] per cent solution.	12.995 [b] per cent solution.	17.42 [b] per cent solution.	17.62 [a] per cent solution.	26.00 [b] per cent solution.	5 [c] per cent solution.
° C.							
0	1.234	....	....	....	0.678	....	....
5	1.024	....	....	....	.577	....	....
6.4	....	0.8990	0.6326	0.5181	....	0.3470	....
10	.875	....	....	....	.503	....	....
15	.755	.7347	.5569	.4306	.442	.2969	0.8122
20	.664	....	....	....	.393	....	....
22	....	....	.4822	.3892	....	.2630	....
25	.583	....	....	....	.352	....	....
30	.517	....	....	....	.319	....	....
35	.460	....	....	....	.288	....	....
40	.414	....	....	....	.263	....	....
45	.370	....	....	....	.235	....	....
50	.335	....	....	....	.215	....	....
55	.305	....	....	....	.198	....	....
60	....	....	....	....	.183	....	....

[a] Bohr, Ann. Phys. Chem., 304, 500 (1899).
[b] Mackenzie, Ann. Phys. Chem., 237, 438 (1877).
[c] Setschenow, Arch. gesammt. Physiol., 8, 1 (1874).

TABLE IX.—*Solubility of carbon dioxide in aqueous solutions of sodium chloride.*[a]

NaCl per liter.	Solubility at—		
	15.2° C.	18.38° C.	21.7° C.
Grams.			
32	0.866	0.795	0.726
64	.760	.702	.630
96	.661	.610	.560
128	.580	.533	.497
160	.515	.483	.437
192	.466	.427	.394

[a] Setschenow, Mémoires de l'acad. impér. des sci. de St.-Pétersb. (7), **22**, No. 6 (1875); Ann. Chim. Phys. (6), **25**, 226 (1892).

TABLE X.—*Solubility of carbon dioxide in aqueous solutions of sodium chloride at 15.2° C.*[a]

NaCl per liter.	Solubility.	NaCl per liter.	Solubility.
Grams.		*Grams.*	
12.9	0.978	78.9	0.728
18.6	.950	105.2	.640
19.7	.944	125.6	.606
25.9	.919	157.8	.530
38.8	.865	210.4	.422
52.6	.802	315.6	.290
63.1	.778		

[a] Setschenow, Mémoires de l'acad. impér. des sci. de St.-Pétersb. (7), **34**, No. 3 (1886); Ann. Chim. Phys. (6), **25**, 226 (1892).

In Table XI there have been collected several isolated determinations by Setschenow, which are given for the sake of completeness.

TABLE XI.—*Solubility of carbon dioxide in aqueous solutions of sodium chloride.*[a]

Composition of solution.	Solubility at—		
	15.2° C.	18.38° C.	21.7° C.
125.6 grams NaCl per liter (A)	0.606	0.550	....
100 c. c. solution A + 95.6 grams water	.776	.705	....
100 c. c. solution A + 296.8 grams water	.885	.807	....
11.7 per cent solution	....	....	0.489
19.7 per cent solution	....	....	.341

[a] Setschenow, Mémoires de l'acad. impér. des sci. de St.-Pétersb. (7), **22**, No. 6 (1875); **34**, No. 3 (1886).

Potassium chloride.

TABLE XII.—*Solubility of carbon dioxide in aqueous solutions of potassium chloride at different temperatures.*[a]

Density of solution.	KCl in solution.	Solubility at—		
		8° C.	15° C.	22° C.
	Per cent.			
1.0211	6.06	0.9880	0.7772	0.6701
1.0527	8.65	.9178	.7768	.6488
1.0796	11.97	.8639	.7202	.5970
1.1488	22.51	.6877	.5707	.4801

[a] Mackenzie, Ann. Phys. Chem., **287**, 438 (1877).

TABLE XIII.—*Solubility of carbon dioxide in aqueous solutions of potassium chloride.*

Setschenow.[a]		Geffcken.[b]		
KCl per liter.	Solubility at 15.2° C.	KCl per liter.	Solubility at—	
			15° C.	25° C.
Grams.		*Grams.*		
94	0.819	31.55	0.9892	0.7695
141	.745	32.23	.9865	.7667
282	.579	77.96	.8875	.6920
....	....	78.93	.8910	.6961

[a] Ann. Chim. Phys. (6), **25**,, 226 (1892).
[b] Zeit. phys. Chem., **49**, 257 (1904).

One other determination has been made by Setschenow,[a] viz, that at 22.4° C. the solubility of carbon dioxide in 14.9 per cent potassium chloride solution is 0.589.

Ammonium chloride.

TABLE XIV.—*Solubility of carbon dioxide in aqueous solutions of ammonium chloride at different temperatures.*[a]

Density of solution.	NH_4Cl in solution.	Solubility at—		
		10° C.	15° C.	22° C.
	Per cent.			
1.0211	6.47	1.0227	0.8253	0.7182
1.0470	8.72	1.0000	.7906	.7022
1.0527	12.73	.9220	.7981	.6840
1.0721	22.23	.8132	.7384	.5998

[a] Mackenzie, Ann. Phys. Chem., **237**, 438 (1877).

TABLE XV.—*Solubility of carbon dioxide in aqueous solutions of ammonium chloride at 15.2° C.*[a]

NH_4Cl per liter.	Solubility.	NH_4Cl per liter.	Solubility.
Grams.		*Grams.*	
1.0	1.005	86	0.897
10.0	.985	129	.858
43.0	.956	172	.819
51.6	.941	258	.770
64.5	.931	....	....

[a] Setschenow, Mémoires de l'acad. impér. des sci. de St.-Pétersb. (7), **22**, No. 6 (1875); **35**, No. 7 (1887); Ann. Chim. Phys. (6), **25**, 226 (1892).

In the first of the above papers Setschenow has recorded that at 21.7° C. the solubility of carbon dioxide in 17.8 per cent of ammonium chloride solution is 0.669.

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[a] Setschenow, Mémoires de l'acad. impér. des sci. de St.-Pétersb. (7), **22**, No. 6 (1875).

Cæsium and rubidium chlorides.

TABLE XVI.—*Solubility of carbon dioxide in aqueous solutions of the chlorides of cæsium and rubidium.*[a]

Solution.	Solubility at—	
	15° C.	25° C.
93.1 grams CsCl per liter	1.000	0.777
58.1 grams RbCl per liter	.991	.770
122.2 grams RbCl per liter	.921	.717

[a] Geffcken, Zeit. phys. Chem., 49, 257 (1904).

Lithium chloride.

TABLE XVII.—*Solubility of carbon dioxide in aqueous solutions of lithium chloride at 15.2° C.*[a]

LiCl per liter.	Solubility.	LiCl per liter.	Solubility.
Grams.		*Grams.*	
16.72	1.035	125.4	0.596
25.08	.899	250.8	.497
50.15	.808	501.5	.120

[a] Setschenow, Ann. Chim. Phys. (6), 25, 226 (1892).

Sodium bromide.

TABLE XVIII.—*Solubility of carbon dioxide in aqueous solutions of sodium bromide at 15.2° C.*[a]

NaBr per liter.	Solubility.
115.1	0.775
460.3	.364
690.4	.221

[a] Setschenow, Ann. Chim. Phys. (6), 25, 226 (1892).

Potassium bromide.

TABLE XIX.—*Solubility of carbon dioxide in aqueous solutions of potassium bromide.*

Setschenow.[a]		Geffcken.[b]		
KBr per liter.	Solubility at 15.2° C.	KBr per liter.	Solubility at—	
			15° C.	25° C.
Grams.		*Grams.*		
83.9	0.908	65.51	0.9783	0.7621
167.7	.819	67.30	.9766	.7619
251.5	.748	125.8	.9100	.7030
503.1	.579	126.7	.9065	.7068

[a] Ann. Chim. Phys. (6), 25, 226 (1892).
[b] Zeit. phys. Chem., 49, 257 (1904).

Potassium iodide.

TABLE XX.—*Solubility of carbon dioxide in aqueous solutions of potassium iodide.*

Setschenow.[a]		Geffcken.[b]		
KI per liter.	Solubility at 15.2° C.	KI per liter.	Solubility at—	
			15° C.	25° C.
Grams.		*Grams.*		
319.1	0.773	93.85	0.9809	0.7678
478.6	.688	95.18	.9835	.7676
957.3	.506	173.24	.9144	.7236
		185.87	.9090	.7166

[a] Ann. Chim. Phys. (6), **25**, 226 (1892).
[b] Zeit. phys. Chem., **49**, 257 (1904).

Sodium nitrate.

TABLE XXI.—*Solubility of carbon dioxide in aqueous solutions of sodium nitrate at 15.2° C.*[a]

$NaNO_3$ per liter.	Solubility.	$NaNO_3$ per liter.	Solubility.
Grams.		*Grams.*	
89.3	0.835	208.4	0.621
104.2	.795	312.6	.495
125.0	.762	416.8	.385
156.3	.709	625.2	.244

[a] Setschenow, Mémoires de l'acad. impér. des sci. de St.-Pétersb. (7), **34**, No. 3 (1886); Ann. Chim. Phys. (6), **25**, 226 (1892).

TABLE XXII.—*Solubility of carbon dioxide in aqueous solutions of sodium nitrate at various temperatures.*[a]

Solution.	Solubility at—		
	15.2° C.	18.38° C.	21.7° C.
17.02 per cent solution	....	0.822	0.551
28.36 per cent solution	....	....	.400
125.4 grams per liter (A)	0.747	.693	....
100 c. c. (A) + 95.54 c. c. water	.876	.798	....
100 c. c. (A) + 286.6 c. c. water	.946	.870	....

[a] Setschenow, Mémoires de l'acad. impér. des sci. de St.-Pétersb. (7), **22**, No. 6 (1875); **34**, No. 3 (1886).

Potassium nitrate.

TABLE XXIII.—*Solubility of carbon dioxide in aqueous solutions of potassium nitrate.*

Setschenow.[a]		Geffcken.[b]		
KNO_3 per liter.	Solubility at 15.2° C.	KNO_3 per liter.	Solubility at—	
			15° C.	25° C.
Grams.		*Grams.*		
58.8	0.959	54.24	1.001	0.7825
117.5	.8902	104.0	.943	.745
168.0	.825	....	....	....
235.1	.781	....	....	....

[a] Mémoires de l'acad. impér. des sci. de St.-Pétersb. (7), **22**, No. 6 (1875); **35**, No. 7 (1887).
[b] Zeit. phys. Chem., **49**, 257 (1904).

In the first of the above papers Setschenow gives the solubility of carbon dioxide in 20.24 per cent solution of potassium nitrate as 0.641 at 22.4° C.

Ammonium nitrate.

TABLE XXIV.—*Solubility of carbon dioxide in aqueous solutions of ammonium nitrate at 15.2° C.*[a]

NH_4NO_3 per liter.	Solubility.	NH_4NO_3 per liter.	Solubility.
Grams.		*Grams.*	
2.8	1.013	101.0	0.962
5.6	1.010	202.1	.911
11.2	1.006	386.0	.819
22.5	.983	404.3	.807
55.0	.989	810.4	.612

[a] Setschenow, Mémoires de l'acad. impér. des sci. de St.-Pétersb. (7), **22**, No. 6 (1875); Ann. Chim. Phys. (6), **25**, 226 (1892).

Ammonium sulphate.

The following figures give two determinations of Setschenow* on the solubility of carbon dioxide in ammonium sulphate solutions:

Grams $(NH_4)_2SO_4$ per liter	72.2	144.4
Solubility at 15.2° C	0.712	0.575

Sodium sulphate.

TABLE XXV.—*Solubility of carbon dioxide in aqueous solutions of sodium sulphate at 15.2° C.*[a]

Na_2SO_4 per liter.	Solubility.	Na_2SO_4 per liter.	Solubility.
Grams.		*Grams.*	
14.22	0.950	94.8	0.620
28.44	.876	142.2	.485
56.88	.753	284.4	.2335
71.10	.700	....	....

[a] Setschenow, Ann. Chim. Phys. (6), **25**, 226 (1892).

TABLE XXVI.—*Solubility of carbon dioxide in aqueous solutions of sodium sulphate at various temperatures.*[a]

Solution.	Solubility at—		
	15.2° C.	18.38° C.	21.7° C.
7.11 per cent solution	....	0.670	....
14.22 per cent solution	....	....	0.391
128.74 grams per liter (A)	0.472	.470	....
100 c. c. (A) +98.04 c. c. water	.771	.660	....
100 c. c. (A) +294.12 c. c. water	.850	.771	....

[a] Setschenow, Mémoires de l'acad. impér. des sci. de St.-Pétersb. (7), **22**, No. 6 (1875); **34**, No. 3 (1886).

*Mémoires de l'acad. impér. des sci. de St.-Pétersb. (7), **22**, No. 6 (1875).

Potassium sulphocyanate.

TABLE XXVII.—*Solubility of carbon dioxide in aqueous solutions of potassium sulphocyanate at 15.2° C.*[a]

KSCN per liter.	Solubility.
Grams.	
326	0.691
489	.590
978	.387

[a] Setschenow, Ann. Chim. Phys. (6), **25**, 229 (1892).

Sodium chlorate.

TABLE XXVIII.—*Solubility of carbon dioxide in aqueous solutions of sodium chlorate at 15.2° C.*[a]

$NaClO_3$ per liter.	Solubility.
Grams.	
233.3	0.625
349.9	.506
699.8	.257

[a] Setschenow, Ann. Chim. Phys. (6), **25**, 229 (1892).

Calcium chloride.

TABLE XXIX.—*Solubility of carbon dioxide in aqueous solutions of calcium chloride at various temperatures.*[a]

Density.	$CaCl_2$ in solution.	Solubility at—			
		8° C.	16½° C.	22° C.	30° C.
	Per cent.				
1.0358	4.3650	0.9423	0.7587	0.6726	0.5957
1.0489	5.7390	.8548	.7260	.6159	.5266
1.0683	8.0453	.8383	.6740	.5809	.4998
1.1387	15.7925	.6315	.5202	.4709	.3945

[a] Mackenzie, Ann. Phys. Chem., **237**, 438 (1877).

Strontium chloride.

TABLE XXX.—*Solubility of carbon dioxide in aqueous solutions of strontium chloride at various temperatures.*[a]

Density.	$SrCl_2$ in solution.	Solubility at—			
		8° C.	16½° C.	22° C.	30° C.
	Per cent.				
1.0873	9.5108	0.7789	0.6633	0.5806	0.5079
1.1159	12.3248	.7367	.5859	.5071	.4386
1.1727	17.7132	.6057	.4727	.4435	.3672
1.3428	31.1937	.2854	.2449	.2474	.2231

[a] Mackenzie, Ann. Phys. Chem., **237**, 438 (1877).

Another determination by Setchenow* is that at 15.2° C. the solubility of carbon dioxide in 3.97 per cent strontium chloride solution is 0.893.

Barium chloride.

TABLE XXXI.—*Solubility of carbon dioxide in aqueous solutions of barium chloride at various temperatures.*[a]

Density.	$BaCl_2$ in solution.	Solubility at—			
		8° C.	16½° C.	22° C.	30° C.
	Per cent.				
1.0684	7.3162	0.9694	0.7441	0.6803	0.5655
1.0916	9.7531	1.0207	.6445	.6072	.5426
1.1372	14.0297	....	.6179	.5235	.4672
1.2731	25.2146	.4949	.6179	.3833	.3152

[a] Mackenzie, Ann. Phys. Chem., **287**, 438 (1877).

Two determinations have been made by Setchenow,* as follows:
At 15.2° C. solubility in 5.2 per cent $BaCl_2$ solution is 0.894.
At 22° C. solubility in 6.94 per cent $BaCl_2$ solution is 0.670.

Magnesium sulphate.

TABLE XXXII.—*Solubility of carbon dioxide in aqueous solutions of magnesium sulphate at 15° to 16° C.*

$MgSO_4$ per liter.	Solubility.
Grams.	
26.5	0.901
40.0	.822
79.5	.669
159.0	.441
318.0	.188

[a] Setschenow, Mémoires de l'acad. impér. des sci. de St.-Pétersb. (7), **35**, No. 7 (1887); Ann. Chim. Phys. (6), **25**, 226 (1892).

In Table XXXII the concentrations have been calculated from tables of the solubility of magnesium sulphate in water, as the original paper gave only the density of the concentrated solution, which was also saturated.

TABLE XXXIII.—*Solubility of carbon dioxide in aqueous solutions of magnesium sulphate at various temperatures.*[a]

Composition of solution.	Temperature.	Solubility.
	° C.	
8.432 grams $MgSO_4$+500 grams water	26.00	0.712
33.73 grams $MgSO_4$+500 grams water	25.00	.586
60.2 grams $MgSO_4$+500 grams water	18.38	.523
15.05 per cent solution	22.40	.310

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[a] Setschenow, Mémoires de l'acad. impér. des sci. de St.-Pétersb. (7), **22**, No. 6 (1875); Ann. Chim. Phys. (6), **25**, 225 (1892).

*Mémoires de l'acad. impér. des sci. de St.-Pétersb. (7), **22**, No. 6 (1875).

Zinc sulphate.

TABLE XXXIV.—*Solubility of carbon dioxide in aqueous solutions of zinc sulphate at 15° to 16° C.*[a]

$ZnSO_4$ per liter.	Solubility.
Grams.	
38.3	0.903
76.7	.783
230.0	.474
460.0	.209

[a] Setschenow, Mémoires de l'acad. impér. des sci. de St.-Pétersb. (7), **35**, No. 7 (1887); Ann. Chim. Phys. (6), **25**, 226 (1892).

In Table XXXIV the concentrations have been calculated from tables of the solubility of zinc sulphate in water, as the original papers gave only the density of the most concentrated solution, which was also saturated.

TABLE XXXV.—*Solubility of carbon dioxide in aqueous solutions of zinc sulphate at various temperatures.*[a]

Composition of solution.	Temperature.	Solubility.
	°*C.*	
9.84 grams $ZnSO_4$+500 grams water	26.00	0.715
39.34 grams $ZnSO_4$+500 grams water	25.00	.593
80.7 grams $ZnSO_4$+500 grams water	18.38	.522

[a] Setschenow, Mémoires de l'acad. impér. des sci. de St.-Pétersb. (7), **22**, No. 6 (1875); Ann. Chim. Phys. (6), **25**, 226 (1892).

Other salts.

TABLE XXXVI.—*Solubility of carbon dioxide in aqueous solutions of different salts.*[a]

Composition of solution.	Temperature.	Solubility.
	°*C.*	
6.27 per cent $Ba(NO_3)_2$ solution	15.2	0.922
8.35 per cent $Ba(NO_3)_2$ solution	22.0	.715
4.10 per cent $Ca(NO_3)_2$ solution	15.2	.923
5.29 per cent $Sr (NO_3)_2$ solution	15.2	.916
12.8 per cent $CaSO_4$ solution	18.38	.672
34 per cent $AgNO_2$ solution	18.38	.648
11.9 per cent $MgCl_2$ solution	22.4	.451

[a] Setschenow, Mémoires de l'acad. imper. des sci. de St.-Pétersb. (7), **22**, No. 6 (1875).

GENERAL CONCLUSIONS.

The following general conclusions may be drawn from the work upon the solubility of carbon dioxide in various solutions:

1. The solubility in salt solutions is less than in an equal volume of water.
2. The solubility of carbon dioxide in water is increased by addition of nitric acid.
3. The solubility of carbon dioxide in sulphuric acid is decreased by the addition of water; likewise the solubility of carbon dioxide

in water is decreased by the addition of sulphuric acid; consequently there is a mixture of sulphuric acid and water, which dissolves a minimum quantity of carbon dioxide.

4. The more concentrated the solutions are, the less carbon dioxide is absorbed.

5. The solubility in solutions of strontium chloride is between that in calcium and barium chlorides.

6. The quantity of carbon dioxide absorbed becomes less as the temperature increases.

7. The solubility is less in sulphate solutions than in chloride solutions, and less in chloride solutions than in nitrate solutions.

8. Solutions of sodium salts absorb carbon dioxide less readily than solutions of similar potassium salts, and solutions of ammonium salts are better solvents than solutions of either sodium or potassium salts.

LIME.

SOLUBILITY OF LIME IN WATER.

Many experimenters have investigated the solubility of lime in water at different temperatures, and on account of the many precautions which must be taken in such determinations the results have not shown a satisfactory agreement. It is essential that the water in which the lime is to be dissolved should be absolutely free from impurities, especially materials of organic origin, which will be shown to possess a very great solvent action on lime. It is also essential in any accurate determinations that the source and impurities of the lime should be known. That there is a difference in the solubility of lime, depending on the source and consequently upon the impurities present, is seen from the determinations of Lamy[a] upon lime obtained from different sources. These results are given in the following table:

Table XXXVII.—*Solubility of lime obtained from different sources.*

Temperature.	Lime in 1,000 parts of solution.		
	From nitrate.	From marble.	Hydrate.
° C.	*Parts.*	*Parts.*	*Parts.*
0	1.362	1.381	1.430
10	1.311	1.342	1.384
15	1.277	1.299	1.344
30	1.142	1.162	1.195
45	.996	1.005	1.033
60	.864	.868	.885
100	.562	.576	.584

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[a] Compt. rend., 86, 333 (1878).

The solubility of lime in water at different temperatures has been investigated by many experimenters [a] and the results of these investigations have been collected in the following table and the accompanying plate:

TABLE XXXVIII.—*Solubility of lime (CaO) in water.*

[Given in grams per liter.]

Temp.	Dalton.	Phillips.	Carles.	Pavesi and Rotondi.	Witt-stein.	Tich-borne.	Maben.
°*C.*							
0							1.318
5							1.309
10							1.298
13				1.274			
15							1,284
15.6	1.29	1.29			1.37	1.35	
19			1.251	1.241			
20							1.264
23				1.228			
25							1.203
30							1,160
35							1,100
40							1.073
45							1.015
50							.982
54.4	1.03						
55							.906
60							.880
65							.828
70							.810
75							.763
80							.734
85							.720
90							.633
95							.606
99							
100	.789				.752	.747	606
109						.560	
120							
150							
190							

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[a] **Dalton**, New System of Chemical Philosophy, Manchester (1808), cited by Phillips, Ann. Chim. Phys. (2), **16**, 213 (1821); Carles, Pharm. Jour. Trans. (3), **4**, 550 (1874); Pavesi and Rotondi, Ber. deutsch. chem. Ges., **7**, 817(1874); Wittstein, Repert. Pharm. (3), **1**, 182 (1848); Boutron and Boudet, Jour. Pharm. (3), **26**, 16 (1854); Tichborne, Chem. News, **24**, 199 (1871); Maben, Pharm. Jour. Trans. (3), **14**, 505 (1883); Lunge, Jour. Soc. Chem. Ind., **11**, 882 (1892); Cabot, ibid., **16**, 417 (1897); Herzfeld, Bied. Centr., **27**, 571 (1898); Guthrie, Jour. Soc. Chem. Ind., **20**, 223 (1901); Herold, Zeit. Elektrochem., **11**, 417 (1905); Tilden and Shenstone, Proc. Roy. Soc., **38**, 33 (1885).

TABLE XXXVIII.—*Solubility of lime* (*CaO*) *in water*—Continued.

[Given in grams per liter.]

Temp.	Lunge.	Cabot.	Herzfeld.	Guthrie.	Herold.	Tilden and Shenstone.
°*C.*						
0		1.36				
5				1.350		
10				1.342		
13						
15		1.31	1.29	1.320		
15.6						
19						1.182
20	1.374		1.23	1.293		
23						
25			1.18	1.254		
30			1.13	1.219		
35			1.08	1.161		
40	1.162		1.04	1.119		
45			.996			
50			.958	.981		
54.4						
55			.902			
60	1.026		.864	.879		
65			.801			
70			.752	.781		
75			.709			
80	.845		.675	.740		
85						
90				.696		
95						
99		.635				
100	.664			.597		
109						
120					0.305	
150					.169	.246
190					.084	

In spite of the lack of satisfactory accord between these various determinations, the results indicate that lime is about twice as soluble[a] at 0° as it is at 100° C., and that the solubility curve approximates a straight line between the temperatures 25° and 100° C. (See figure 1.)

SOLUBILITY OF LIME IN AQUEOUS SOLUTIONS.

Ammonium chloride.

There are many qualitative statements in the literature that lime is much more soluble in ammonium chloride solutions than in water. The quantitative results obtained by Noyes and Chapin[b] are given in the following table:

TABLE XXXIX.—*Solubility of lime in ammonium chloride solutions at 25° C.*

Ammonium chloride per liter.	Lime per liter.
Grams.	*Grams.*
0.0	1.134
1.164	1.631
2.328	2.201
4.655	3.348

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[a] This result is also given by Goldammer, Pharm. Centr., 26, 442, 455 (1885); abstr. in Jour. Soc. Chem. Ind., 5, 450 (1866).

[b] Zeit. phys. Chem., 28, 518 (1899).

From this table it will be seen that by increasing the quantity of ammonium chloride in the solution the solubility of lime is also

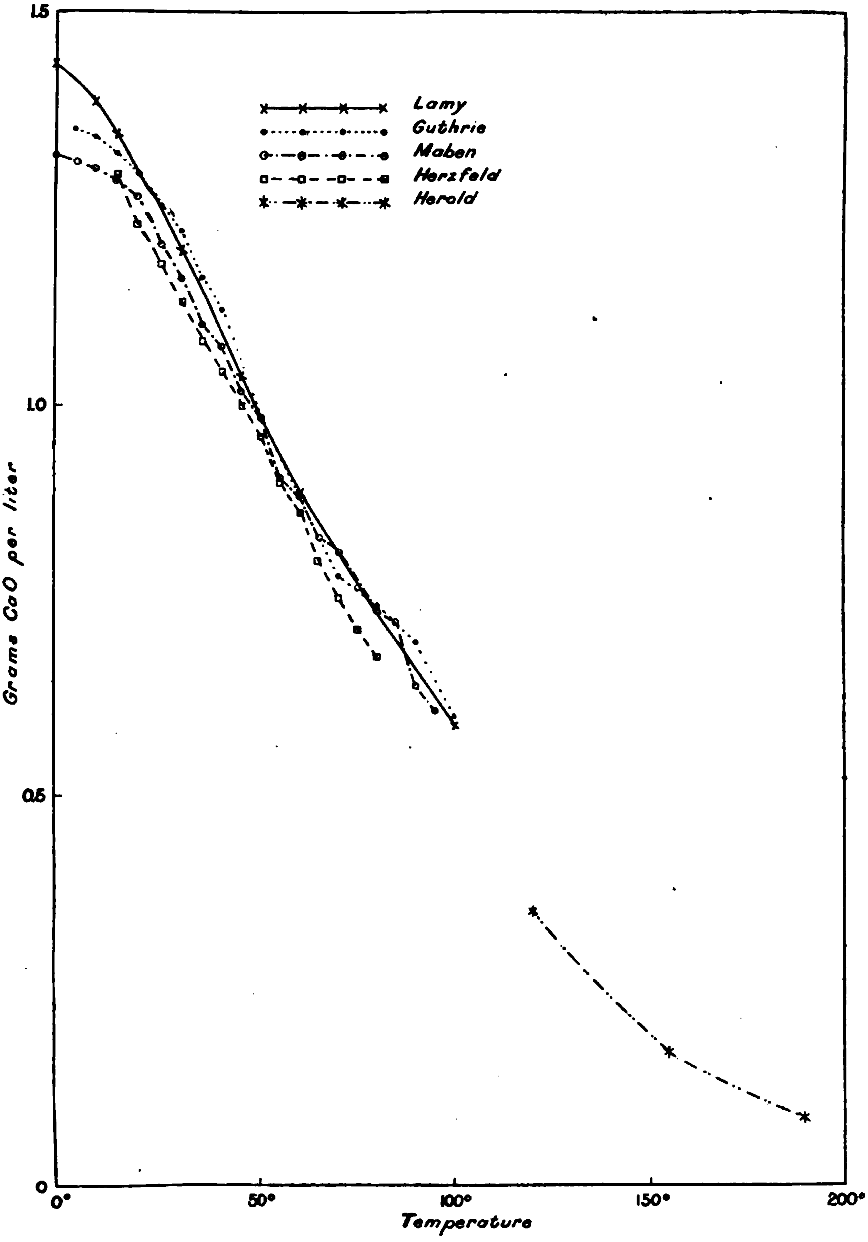

FIG. 1.—Solubility of lime in water at various temperatures according to various experiments.

increased, and at the concentrations employed the increase is nearly proportional to the concentration of ammonium chloride.

Sodium chloride.

Lime is more soluble in sodium chloride solutions than in pure water. According to Lunge,[a] at 50° C. a sodium chloride solution (5 to 10 per cent) dissolves about 35 per cent more lime than does water at the same temperature. The solubility for different concentrations of sodium chloride at different temperatures has been given by Cabot[b] as follows:

TABLE XL.—*Solubility of lime in sodium chloride solutions.*

NaCl per liter.	CaO per liter.		
	0° C.	15° C.	99° C.
Grams.	*Grams.*	*Grams.*	*Grams.*
0	1.36	1.31	0.635
30	1.813	1.703	.969
60	....	1.824	1.004
120	1.86	1.722	1.015
240	1.36	1.274	.771
Saturated.	1.054	.929	.583

With increase of sodium chloride in solution the solubility of lime increases to a maximum and then decreases again until the saturation point for sodium chloride is reached.

These results are confirmed by the experiments of Maigret[c] upon the solubility of lime in sodium chloride solutions. The results also show that the presence of sodium hydroxide causes a decrease in the quantity of lime in solution. The following table gives the results of this work:

TABLE XLI.—*Solubility of lime in sodium chloride solutions containing various quantities of sodium hydroxide.*

NaCl per liter.	CaO per liter.		
	No NaOH.	0.8 gram NaOH per liter.	4.0 grams NaOH per liter.
Grams.	*Grams.*	*Grams.*	*Gram.*
0	1.3	0.8	0.22
5	1.4	.9	....
10	1.6	1.0	....
25	1.7	1.1	....
50	1.8	1.25	....
75	1.9	1.4	.55
100	1.85	1.4	....
125	1.7	1.3	....
150	1.65	1.25	.44
175	1.6	1.2	....
182	1.6	1.2	....
200	1.55	1.1	....
225	1.4	1.0	....
250	1.3	.9	....
275	1.2	.7	....
300	1.1	.7	.22
314	1.0	....	....

[a] Jour. Soc. Chem. Ind., 11, 882 (1892).

[b] Jour. Soc. Chem. Ind., 16, 417 (1897).

[c] Bul. Soc. Chim. (3), 33, 631 (1905).

Potassium chloride.

According to Lunge,[a] at 50° C. a potassium chloride solution (5 to 10 per cent) dissolves about 35 per cent more lime than does water at the same temperature. The solubility for different concentrations of potassium chloride at different temperatures has been given by Cabot[b] as follows:

TABLE XLII.—*Solubility of lime in potassium chloride solutions.*

KCl per liter.	CaO per liter.		
	0° C.	15° C.	99° C.
Grams.	*Grams.*	*Grams.*	*Gram.*
0	1.36	1.31	0.635
30	1.701	1.658	.788
60	1.725	1.674	.876
120	1.718	1.606	.894
240	1.248	1.199	.612
Saturated.	1.21	....	....

The solubility increases with increase of potassium chloride to a maximum and then decreases again as the concentration of potassium chloride approaches the saturation point.

Calcium chloride.

It might be expected that the solubility of lime in the solution of a salt yielding a common ion would be depressed. There are indications that this actually happens at lower temperatures and in the more dilute solutions of calcium chloride. In the more concentrated solutions, however, this solubility is augmented, as will be observed from the following table by Lunge[b] and Zahorsky.[c]

TABLE XLIII.—*Lime dissolved at different temperatures by various solutions of calcium chloride.*

$CaCl_2$	CaO per 100 c. c. solution.				
	20° C.	40° C.	60° C.	80° C.	100° C.
Per cent.	*Gram.*	*Gram.*	*Gram.*	*Gram.*	*Gram.*
0	0.1374	0.1162	0.1026	0.0845	0.0664
5	.1370	.1160	.1020	.0936	.0906
10	.1661	.1419	.1313	.1326	.1389
15	.1993	.1781	.1706	.1736	.1842
20	[a] 1857	.2249	.2204	.2295	.2325
25	[a].1661	[a] 3020	.2989	.3261	.3710
30	[a].1630	[a].3684	.3664	.4122	.4022

[a] Oxychloride separated out.

Lunge has pointed out from these results that solutions up to 10 per cent calcium chloride at ordinary or slightly raised temperatures alter the solubility very little from that in pure water. At the higher temperatures the presence of calcium chloride increases the solubility of lime proportionately with the quantity of calcium chloride, except where the phenomenon is complicated by precipitation of the solid oxychloride. The changes in solubility due to changes of temperature are not so great as the changes consequent upon changes in concentration of calcium chloride.

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[a] Jour. Soc. Chem. Ind., **11**, 882 (1892). [b] Jour. Soc. Chem. Ind., **16**, 417 (1897).
[c] Zeit. anorg. Chem., **3**, 34 (1893).

The recovery of manganese peroxide in the Weldon process is brought about by the action of lime upon the manganous salts. The presence of considerable quantities of calcium chloride is essential, and according to Lunge the most natural explanation is that it serves as a solvent for lime, as lime is much more soluble in hot solutions of calcium chloride than in water. This increased solubility has been attributed to the formation of an oxychloride in solution. That this explanation is not sufficient follows from a consideration of the relative solubilities of the oxychloride and of lime. Of two substances which may separate out as solid phase under any conditions the stable solid is that one whose solubility in the liquid is least, or which, after the precipitation has taken place, leaves the solution least concentrated. As the oxychloride separates out at the higher concentrations, it follows that the content of free lime in the solution is less than if the solid phase had been calcium hydroxide. The increased solubility of lime in calcium chloride solutions of the higher concentrations can not therefore be satisfactorily explained on the ground of the formation of oxychloride in solution.

The crystalline precipitate obtained by heating lime in a concentrated solution of calcium chloride was first observed by Buchholtz[a] and later by Tromsdorf.[a] At first it was supposed to be a modification of lime, but Berthollet[a] subsequently showed it to be a compound of lime with calcium chloride. The ratio of lime to calcium chloride has been definitely determined by many experimenters as three to one, but the number of molecules of water of crystallization has been variously determined. Rose,[b] Ditte,[c] and André[d] have ascribed to it the formula $3CaO.CaCl_2.16H_2O$; Beesley[e] has given it the formula $3CaO.CaCl_2.14H_2O$; while Rose,[f] Precht,[g] Grimshaw,[h] and Zahorsky[i] indicate the formula $3CaO.CaCl_2.15H_2O$.

This compound is formed in large quantities in the production of ammonia by the action of lime on ammonium chloride, and all the above work upon its composition has been upon the compound obtained by dissolving lime in warm or hot concentrated calcium chloride solutions and allowing it to settle after filtration. Upon standing, large crystals of the oxychloride separate. These are decomposed by water and by alcohol. Ditte has shown that when the oxychloride is treated with water the solution contains all the calcium chloride and part of the lime, while the residue of lime remains as a fine powder. This decomposition does not take place at 10° C. after the solution has reached the concentration of 85 grams calcium chloride per liter. Alcohol acts similarly, and at 17° C. no decomposition occurs if the alcohol contains 130 grams calcium chloride per liter, but calcium oxychloride passes into solution unchanged. Zahorsky has also proved that sodium, potassium, and ammonium chlorides in solution all decompose the oxychloride of calcium, free lime being left as a fine powder. Glycerol, however, has no decomposing influence upon the oxychloride, but dissolves it readily in the cold, the solution undergoing no decomposition upon heating. When an equal volume of water is added to the solution in glycerol, decomposition takes place, lime separating.

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[a] See Berthollet, Essai de Statique Chimique, **1**, 350.

[b] Schweig, Jour., **29**, 155 (1820).

[c] Compt. rend., **91**, 576 (1880).

[d] Compt. rend., **92**, 1452 (1881); Ann. Chim. Phys. (6), **3**, 66 (1884).

[e] Phar. Jour. Trans., **9**, 568 (1850).

[f] Schweig. Jour., **29**, 155 (1820).

[g] See Zahorsky, Zeit. anorg. Chem., **3**, 34 (1893).

[h] Chem. News, **30**, 280 (1874).

[i] Zeit. anorg. Chem., **3**, 34 (1893).

Sodium and potassium hydroxides.

According to Pelouze[a] 100 parts of a solution containing 1 part of sodium or potassium hydroxide dissolves not more than one fifty-thousandth of 1 part of lime.

The following results by d'Anselme[b] prove that the solubility of lime in sodium hydroxide solutions decreases with increasing concentrations of the caustic alkali and also with rise in temperature:

TABLE XLIV.—*Solubility of lime in solutions of sodium hydroxide.*

NaOH per liter.	CaO per liter.			
	20° C.	50° C.	70° C.	100° C.
Grams.	*Grams.*	*Gram.*	*Gram.*	*Gram.*
0.0	1.17	0.88	0.75	0.54
0.4	.94	.65	.53	.35
1.6	.57	.35	.225	.14
2.67	.39	.20	.11	.05
5.0	.18	.06	.04	.01
8.0	.11	.02	.01	Traces.
20.0	.02	Traces.	.00	.00

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[a] Ann. Chim. Phys. (3), 33, 5 (1851).

[b] Bul. Soc. Chim. (3), 29, 936 (1903).

Calcium sulphate.

The mutual solubility of gypsum in lime solutions and of calcium hydroxide in gypsum solutions has recently been determined at 25° C. in this laboratory by Cameron and Bell[a] with the following results:

TABLE XLV.—*Mutual solubility of gypsum and lime at 25° C.*

$CaSO_4$ per liter.	CaO per liter.	Solid phase.
Grams.	*Grams.*	
0.000	1.166	$Ca(OH)_2$.
.391	1.141	$Ca(OH)_2$.
.666	1.150	$Ca(OH)_2$.
.955	1.215	$Ca(OH)_2$.
1.214	1.212	$Ca(OH)_2$.
1.588	1.222	$Ca(OH)_2$, $CaSO_4.2H_2O$.
1.634	.939	$CaSO_4.2H_2O$.
1.722	.611	$CaSO_4.2H_2O$.
1.853	.349	$CaSO_4.2H_2O$.
1.918	.176	$CaSO_4.2H_2O$.
2.032	.062	$CaSO_4.2H_2O$.
2.126	.000	$CaSO_4.2H_2O$.

It will be seen from these results that with increasing lime content in the solution the solubility of gypsum is steadily depressed. With increasing amounts of gypsum in the solution the solubility of lime seems to be nearly the same as in pure water. These results have been recently confirmed by further work in this laboratory by Bell and Taber.

Calcium nitrate.

The following table by Cameron and Robinson[b] gives the content of free lime in various solutions of calcium nitrate at 25°.

TABLE XLVI.—*Solubility of lime in calcium nitrate solutions at 25°.*

Density $\frac{25°}{25°}$.	CaO as $Ca(OH)_2$.		$Ca(NO_3)_2$.	
	In 100 c. c.	In 100 grams H_2O.	In 100 c. c.	In 100 grams H_2O.
Grams.	*Gram.*	*Gram.*	*Grams.*	*Grams.*
1.0249	0.095	0.096	3.35	3.38
1.0484	.105	.109	8.18	8.52
1.0940	.120	.125	12.91	13.42
1.1383	.170	.181	19.43	20.73
1.1840	.171	.187	26.49	28.98
1.2101	.180	.198	29.82	32.84
1.2287	.190	.212	32.97	36.83
1.2290	.191	.213	33.27	37.55
1.2541	.200	.224	35.87	40.25
1.2581	.203	.230	37.04	41.98
1.2826	.226	.260	40.88	47.00
1.2905	.229	.263	41.08	47.16
1.3337	.277	.332	48.99	58.67
1.3735	.346	.429	50.88	69.40
1.4195	.440	.545	63.93	83.03
1.4840	.331	.449	73.58	99.70
1.5330	.263	.371	81.91	115.50
1.5809	.203	.303	90.38	135.30
1.5842	.000	.000	91.84	139.30

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[a] Jour. Am. Chem. Soc., 28, 1220 (1906); Bul. No. 33, Bureau of Soils, U. S. Dept. Agr. (1906).

[b] Jour. Phys. Chem., 11, 273 (1907).

These results are plotted in the accompanying diagram (fig. 2), in which four distinct curves are seen. In order to determine the composition of the solid phases along each of these curves the triangular diagram method of Schreinemakers and Bancroft was employed, and the following table gives the composition of the solutions and of the corresponding solid phases with adhering mother liquor.

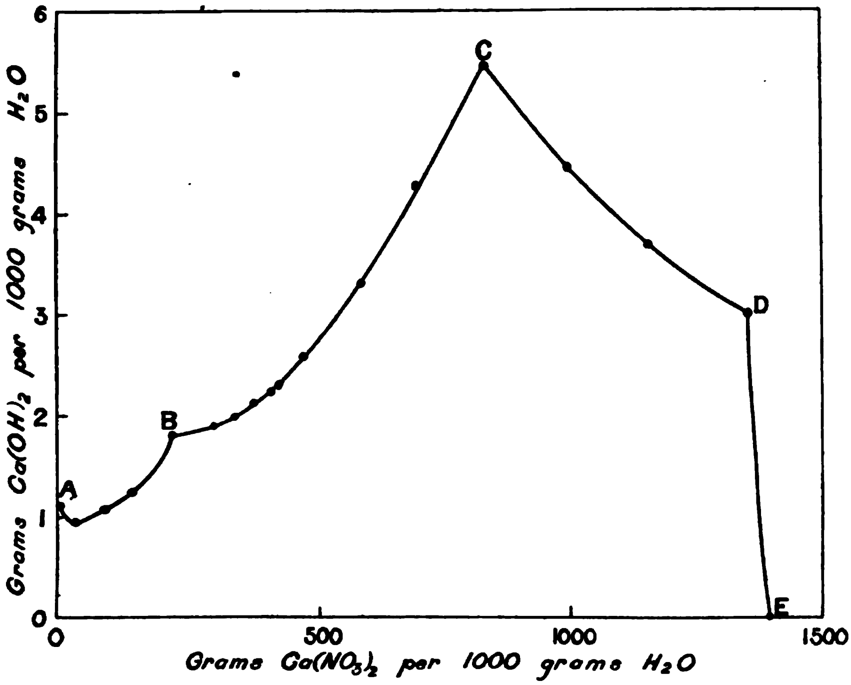

FIG. 2.—Solubility of lime in solutions of calcium nitrate at 25° C.

TABLE XLVII.—*Composition of solutions and solid residues at 25°.*

Point.	Solution.		Point.	Precipitate with adhering solution.	
	CaO.	N_2O_5.		CaO.	N_2O_5.
	Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
F......	1.21	2.15	F'......	40.85	1.00
G......	4.16	7.80	G'......	37.70	4.09
H......	7.77	14.70	H'......	33.26	7.20
I......	9.34	17.84	I'......	29.73	9.87
J......	9.83	18.77	J'......	27.49	11.60
K......	14.21	26.87	K'......	38.59	15.71
L......	17.20	33.32	L'......	31.64	36.36
M......	18.50	35.33	M'......	31.72	37.21

From the diagram (figure 3) it will be seen that the extension of the lines F F' and G G' meet in a point corresponding to solid calcium hydroxide. This substance, therefore, was the solid phase in contact with the solutions represented by the curve A B.

It is evident that the lines joining the points representing the composition of the solutions and their corresponding precipitates for the second branch of the curve, when extended, do not meet at a common point. The precipitate is therefore of variable composition, and since there can be only one solid phase present, it must be a series of solid solutions containing calcium oxide, nitric oxide, and probably water.

The residues along the third branch of the curve proved to be a substance occurring in long acicular crystals. As scaled off from the diagram its percentage composition is CaO, 39.5; N_2O_5, 38.0, and H_2O, 22.5; corresponding to the compound $2CaO.N_2O_5.3\frac{1}{2}H_2O$, and is identical with the one described by Werner.[a]

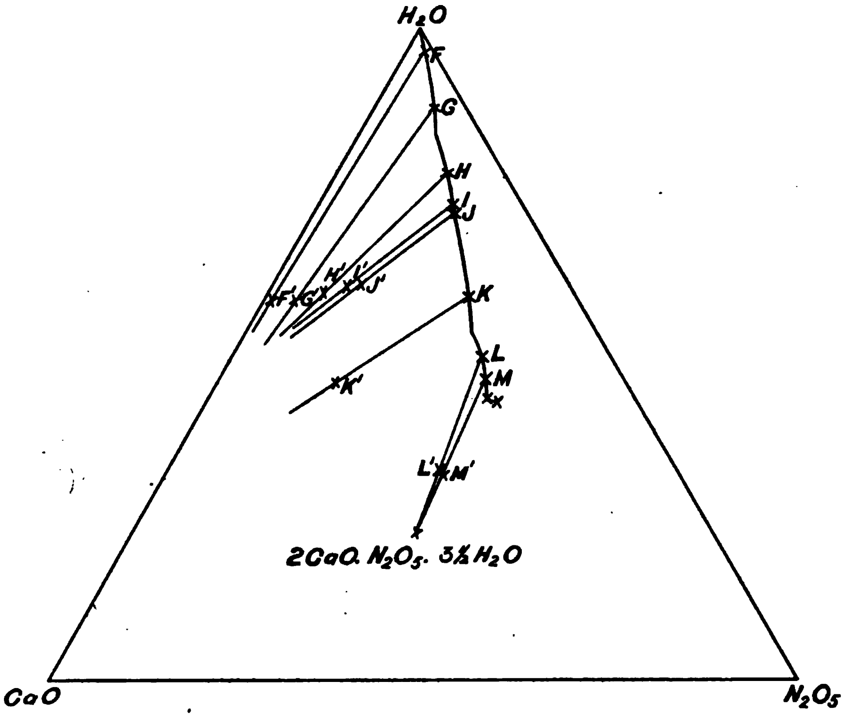

FIG. 3.—Triangular diagram showing the composition of the solutions and of the solid phases in contact with the solutions at 25° C., where there are present lime, calcium nitrate, and water.

The solid phase in contact with the solutions along the fourth branch of the curve was undoubtedly the well-known normal nitrate $Ca(NO_3)_2.4H_2O$, and no further attempt was made to demonstrate its composition. The data for the "constant" solutions have been brought together in the following table:

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[a] Ann. Chim. Phys. (6), **27**, 570 (1892); Compt. rend., **115**, 169 (1892).

TABLE XLVIII.—*Data for the "constant" solutions in the system, calcium nitrate, lime, and water at 25° C.*

Points.	Solid phases in contact with solution.	Concentration of respective solutions; grams per 100 grams H_2O.	
		CaO as $Ca(OH)_2$.	$Ca(NO_3)_2$.
A	$Ca(OH)_2$	0.118	0.0
B	$Ca(OH)_2$, and solid solution ($CaO.xN_2O_5.yH_2O$)	.170	20.73
C	Solid solution ($CaO.xN_2O_5.yH_2O$) and $CaO.N_2O_5.3\frac{1}{2}H_2O$	.440	83.03
D	$CaO.N_2O_5.3\frac{1}{2}H_2O$, and $Ca(NO_3)_2.4H_2O$	.203	135.3
E	$Ca(NO_3)_2.4H_2O$	.000	139.30

Glycerol.

The following table gives the results of Berthelot [a] upon the solubility of lime in glycerol solutions.

TABLE XLIX.—*Solubility of lime in glycerol solutions at 5° C.*

Glycerol per 100 c. c. solution.	CaO per 100 c. c. solution.
Grams.	*Gram.*
1	0.165
2	.186
2.50	.192
2.86	.196
5	.240
10	.370

The results of Carles [b] are in accord with these, showing that as the content of the solution in glycerol becomes greater, the solubility of lime also increases.

TABLE L.—*Solubility of lime in glycerol solutions.*

Solution containing—		CaO dissolved.
Water.	Glycerol.	
Grams.	*Grams.*	*Grams.*
1,000	0	1.251
1,000	50	1.865
1,000	100	2.583
1,000	200	4.040
1,000	400	6.569

The presence of glycerol in solution increases the solubility of lime, as the following table by Puls [c] indicates:

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[a] Ann. Chim. Phys. (3), **46**, 173 (1856). [b] Pharm. Jour. Trans. (3), **4**, 550 (1874).
[c] Jour. prakt. Chem., **123**, 83 (1877).

TABLE LI.—*Solubility of lime in glycerol solutions.*

Glycerol per 100 grams solution.	CaO per 100 grams solution.	Glycerol per 100 grams solution.	CaO per 100 grams solution.
Grams.	*Gram.*	*Grams.*	*Grams.*
0.0	0.148	10.00	0.370
2.00	.186	26.97	.595
2.50	.192	37.91	.852
2.86	.196	51.15	1.434
5.00	.240		

The following table contains the results of Herz and Knoch:[a]

TABLE LII.—*Solubility of lime in glycerol solutions at 25° C.*

Density $\frac{25°}{25°}$	Glycerol in solvent.	$Ca(OH)_2$ per liter.
	Per cent.	*Grams.*
1.0003	0.0	1.59
1.0244	7.15	3.01
1.0537	20.44	4.51
1.0842	31.55	8.33
1.1137	40.95	14.80
1.1356	48.70	16.30
1.2072	69.20	35.40

Mannite.

In mannite solutions also Berthelot[b] has found that the solubility of lime is increased. The results are given in the following table:

TABLE LIII.—*Solubility of lime in mannite solutions at 5° C.*

Mannite per 100 c. c. solution.	CaO per 100 c. c. solution.	Mannite per 100 c. c. solution.	CaO per 100 c. c. solution.
Grams.	*Gram.*	*Grams.*	*Gram.*
0.0	0.148	1.37	0.194
.096	.154	1.60	.207
.192	.155	1.92	.225
.96	.186	2.40	.255
1.09	.190	4.80	.372
1.20	.193	9.60	.753

Sugar.

The use of lime to neutralize the acid employed in the settling tanks in sugar factories makes the subject of the solubility of lime in sugar solutions one of prime importance. Considerable work has been done on this subject and the results are not altogether concordant. Owing to the fact that sugar and lime form addition compounds the quantity of lime added to a given sugar solution should be taken into account, as the solid phase resulting contains considerable percentages of sugar. Several formulas have been ascribed to the double compound obtained by adding lime to sugar solutions at ordinary temperature. Péligot,[c] Soubeiran,[d] and Benedikt[e] have recorded the compound $C_{12}H_{22}O_{11}.CaO$; Soubeiran found another compound, $2C_{12}H_{22}O_{11}.3CaO$; and Péligot[a] and Dubrunfaut[b] have recorded the compound $C_{12}H_{22}O_{11}.3CaO$. The last author has also determined the ratio of lime to sugar in saturated solutions at different temperatures. The molecular ratio of lime to sugar is eight times as great at or below 0° as it is at 100° C. Péligot[c] has determined the composition of the solid phase in contact with a series of solutions in which the sugar content varies from 2.5 to 40 grams of sugar per 100 grams of water The composition of the solid phase was found to vary continuously from 13.8 per cent to 21.0 per cent lime, thus indicating that lime and sugar form a series of solid solutions, of which the above recorded "compounds" are members. The so-called solubility of lime in sugar solutions is in fact, then, the quantity of lime in the sugar solution, the solid phase being one of the above described solid solutions. When these solids are heated with water the solutions cloud, as the quantity of lime in hot sugar solutions is very much less than in cold solutions. On cooling again the solutions clear up. The following results of Lamy[d] show this to be the case in 10 per cent sugar solutions. The solubility in water at the same temperature has been given, and it will be seen that sugar increases the solubility much more in cold solutions than it does when the solutions are hot.

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[a] Zeit. anorg. Chem., **46**, 193 (1905).

[b] Ann. Chim. Phys. (3), **46**, 173 (1856).

[c] Ann. Chim. Phys. (2), **67**, 113 (1838); Compt. rend., **32**, 333 (1851).

[d] Jour. Pharm. (3), **1**, 469 (1842).

[e] Ber. deutsch. chem. Ges., **6**, 413 (1873).

TABLE LIV.—*Solubility of lime in water and in 10 per cent sugar solutions.*

Temperature.	CaO per 1,000 grams 10 per cent sugar solution.	CaO per 1,000 grams water.
° C.	*Grams.*	*Grams.*
100	15.5	6.0
70	23.0	7.9
50	53.0	9.6
30	120.5	11.7

In the following table there have been recorded the results of Berthelot[e] upon the solubility of lime in various sugar solutions:

TABLE LV.—*Solubility of lime in sugar solutions at 5° C.*

Sugar per 100 c. c. solution.	CaO per 100 c. c. solution.	Sugar per 100 c. c. solution.	CaO per 100 c. c. solution.
Grams.	*Gram.*	*Grams.*	*Grams.*
0.0	0.148	1.200	.316
.096	.154	1.386	.326
.191	.172	1.660	.364
.400	.194	2.000	.433
.960	.264	2.401	.484
1.058	.281	4.850	1.031

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[a] Jour. Pharm. (3), **19**, 324 (1851).

[b] Compt. rend., **32**, 498 (1851).

[c] Compt. rend., **32**, 333 (1851).

[d] See Weisberg. Bul. Soc. Chim. (3), **23**, 740 (1900).

[e] Ann. Chim. Phys. (3), **46**, 173 (1856).

Weisberg[a] has collected the data of several authors upon the solubility of lime in sugar solutions and has calculated the ratio of lime to sugar in the solution. Also in the following table are the results obtained by using different quantities of lime with which to saturate the solutions. In all probability the quantity of lime has caused a marked change in the quantity of sugar in the solution by the union of lime and sugar in the solid phase.

TABLE LVI.—*Solubility of lime in sugar solutions according to various authors.*

Berthelot.		Péligot.		Petit.		Schatten.	
Sugar per 100 c. c. solution.	CaO per 100 grams sugar.	Sugar per 100 c. c. solution.	CaO per 100 grams sugar.	Sugar per 100 c. c. solution.	CaO per 100 grams sugar.	Sugar per 100 c. c. solution.	CaO per 100 grams sugar.
Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
0.400	48.50	2.33	16.00	1.71	16.4	1	29.10
.960	27.48	4.64	18.06	3.52	16.4	2	22.70
1.058	26.57	6.97	20.33	4.275	16.4	3	20.95
1.386	23.52	9.31	22.10	6.84	18.4	6	19.66
1.660	21.92	11.39	22.40	8.55	20.5	8	20.64
2.000	21.65	13.47	22.70	10.40	25.3	11	23.17
2.401	20.16	15.55	23.00	17.10	25.7	13	24.23
4.850	21.15	17.63	23.15	22.80	27.3	16	26.26
....	....	21.32	24.69	....	....	....	....

TABLE LVII.—*Solubility of lime in sugar solutions according to Weisberg, showing the effect of adding lime in varying quantities.*

[T=16° C.]

CaO in excess.		CaO in great excess.	
Sugar per 100 c. c. solution.	CaO per 100 grams sugar.	Sugar per 100 c. c. solution.	CaO per 100 grams sugar.
Grams.	*Grams.*	*Grams.*	*Grams.*
0.7814	37.9	0.625	71.6
.912	32.3	.964	53.4
1.400	30.5	2.084	36.0
1.693	28.9	3.028	32.3
4.754	27.7	3.451	31.7
5.73	27.1	4.168	30.2
10.59	27.5	4.880	28.7
11.20	27.2	5.73	28.3
12.50	27.3	6.12	27.4
13.93	27.9	6.25	27.7
14.49	27.5	6.51	27.5
16.41	28.0	7.55	27.9
....	....	8.20	27.3

The following table by Weisberg[b] shows the different solubility of quicklime, of calcium hydroxide, and of slaked lime. The apparent difference may probably be ascribed to the nonattainment of equilibrium conditions.

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[a] Bul. Soc. Chim. (3), **21**, 773 (1899).

[b] Bul. Soc. Chim. (3), **23**, 740 (1900).

TABLE LVIII.—*Solubility of quicklime and of slaked lime in sugar solutions at 15° to 16° C.*

CaO.		Ca(OH)$_2$.		Ca(OH)$_2$+H$_2$O.	
Sugar per 100 c. c. solution.	CaO per 100 grams sugar.	Sugar per 100 c. c. solution.	CaO per 100 grams sugar.	Sugar per 100 c. c. solution.	CaO per 100 grams sugar.
Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
13.00	27.75	13.00	25.40		
11.34	27.57	11.96	25.45	11.18	22.40
10.30	27.87	10.87	25.40	10.40	22.90
9.67	27.61	9.67	25.00		
8.27	27.49	8.90	24.74	8.68	22.80
7.64	27.50	8.06	24.72	7.28	21.70
6.84	27.42	6.97	24.50	6.29	20.90
5.77	27.80	5.46	24.50	5.22	20.55
4.73	27.90	4.52	24.23	4.03	20.60
3.95	27.73	3.56	23.60		
3.02	27.78	2.57	23.40		
2.29	27.93	1.85	23.30	2.91	20.05

Finally, Weisberg has compared the solvent action of hot sugar solutions on lime with that of cold sugar solutions.

TABLE LIX.—*Solubility of various samples of lime in hot and cold sugar solutions.*

CaO.				Ca(OH)$_2$.				Ca(OH)$_2$+H$_2$O.			
Ordinary temperature.		80° C.		Ordinary temperature.		90° C.		Ordinary temperature.		90° C.	
Sugar per 100 c. c. solution.	CaO per 100 grams sugar.	Sugar per 100 c. c. solution.	CaO per 100 grams sugar.	Sugar per 100 c. c. solution.	CaO per 100 grams sugar.	Sugar per 100 c. c. solution.	CaO per 100 grams sugar.	Sugar per 100 c. c. solution.	CaO per 100 grams sugar.	Sugar per 100 c. c. solution.	CaO per 100 grams sugar.
Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
13.68	27.8	10.97	21.18	12.13	25.5	8.16	7.50				
10.76	27.6	7.49	16.60	11.59	26.0	7.12	6.84	11.49	23.1	8.79	11.78
6.56	27.7	4.58	16.15	9.15	26.0	5.72	6.36	8.85	23.1	6.29	8.18
4.00	27.4	2.68	13.59	8.68	25.5	5.62	7.67	5.67	23.1	3.95	7.65
4.43	27.8	2.78	8.85								

GENERAL CONCLUSIONS.

1. The apparent solubility of lime in aqueous solutions is greatly dependent on its origin, and therefore on the impurities it contains.

2. The solubility of lime at 0° C. is approximately twice its solubility at 100° C. The temperature-solubility curve approximates a straight line.

3. The solubility of lime in dilute solutions of the chlorides of sodium, potassium, and ammonium is greater than in pure water. The solubility curves for solutions of the chlorides of sodium and potassium have maximum points, and in saturated solutions the solubility is less than in pure water.

4. The solubility of lime in very dilute solutions of calcium chloride seems to be less than in pure water, but as the concentration increases the solubility is raised much above that in pure water, especially at higher temperatures.

5. At lower temperatures and in the more concentrated solutions of calcium chloride the stable solid phase is calcium oxychloride.

6. The presence of other hydroxides depresses markedly the solubility of lime.

7. The presence of gypsum does not appreciably affect the solubility of lime.

8. In contact with very dilute solutions of calcium nitrate, lime passes into solution as such, the solubility increasing with concentration of nitrate; at higher concentrations the stable solid is one of a series of solid solutions, the content of lime still increasing with increase of nitrate; at still higher concentrations the stable solid is a basic nitrate of definite composition, and the concentration of lime in solution falls with increase of nitrate; finally, at very high concentrations the neutral nitrate separates as a solid phase.

9. In solutions of glycerol or mannite the solubility of lime is increased markedly with increase of concentration of the carbohydrate.

10. When lime is brought into contact with sugar solutions the ratio of lime to sugar in the solid varies continuously with the composition of the solution, and consequently the solid compound resulting when lime is added in excess to a sugar solution is one of a series of solid solutions.

11. Cold sugar solutions have a much greater solvent action upon lime than have the same solutions when hot. Heating tends to precipitate one of the solid solutions described above.

12. The ratio of lime to sugar in solution depends on the temperature and on the concentration.

CALCIUM CARBONATE.

MODIFICATIONS OF CALCIUM CARBONATE.

The formation of carbonates in nature has been the subject of much research by chemical geologists.[a] Two forms of calcium carbonate are common, calcite and aragonite, and there seems to be good reason for believing that at the higher temperatures and in salt solutions aragonite is the stable solid phase. Watson[b] states that above 30° C. aragonite is the stable form of calcium carbonate in the presence of solutions of sodium chloride or ammonium chloride. Below that temperature, calcite is stable.

The experiments of Foote[c] have shown that at ordinary temperatures calcite is the stable form of calcium carbonate in solutions of carbon dioxide and also in mixed solutions of potassium carbonate and oxalate. The solubility of calcite is shown by electrical conductivity to be less than that of aragonite in carbon dioxide solutions. The conductivity of solutions saturated with carbon dioxide and calcium carbonate, either as calcite or aragonite, was measured at different temperatures. The following table gives the ratio of the conductivities.

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[a] For a review of the literature see Vater, Zeit. Kryst., **21**, 433 (1893).

[b] Chem. News, **63**, 109 (1891).

[c] Zeit. phys. Chem., **33**, 740 (1900).

TABLE LX.—*Ratio of conductivity of solutions of calcite and aragonite in water saturated with carbon dioxide.*

Temperature.	$\frac{\text{Aragonite}}{\text{Calcite}}$.
°C.	
8	1.147
25	1.130
41	1.124
48	1.115

It is apparent that the solubility of aragonite is higher than that of calcite, and therefore that calcite is the stable solid phase under these conditions. The ratio is smaller at higher temperatures, indicating that the solubility curves are approaching one another, and that at some higher temperature aragonite would probably become the stable phase. The effect of various salts has not been closely investigated.

A large amount of chemical work and of speculation has been done upon the conditions of the formation of dolomite in nature. The theory that dolomite resulted from the action of vapors of volcanic origin upon limestone rocks has long since been abandoned. All the authorities are now agreed that dolomite has been deposited from aqueous solution, either by deposition of the carbonates of calcium and magnesium together or by the action of water carrying magnesium salts on some form of calcium carbonate. In nearly all the experiments upon the artificial formation of dolomite high temperature has been necessary. By heating a solution of magnesium sulphate with calcium carbonate in a sealed tube to 200° C. von Morlot[a] has obtained dolomite; Favre[b] used a solution of magnesium chloride; Hoppe-Seyler[c] used a solution of magnesium sulphate and calcium carbonate saturated with carbon dioxide above 100° C., and also confirmed the results of von Morlot and of Favre. Hunt[d] mixed equivalent quantities of the chlorides of magnesium and calcium and added sodium carbonate to the solution. At high temperature dolomite was formed. In all the above work calcium carbonate in the form of calcite was employed. Klement[e] has investigated the action of magnesium solutions upon aragonite under various conditions. He finds that at about 60° C. magnesium sulphate in saturated sodium chloride solutions begins to react upon aragonite to form dolomite, while under like conditions there is no reaction upon calcite. The extent of reaction increases with the time of contact, with the temperature, and with the concentration of salt in solution. There seems to be a maximum amount of magnesium carbonate in the solid for each temperature. At 91° C. 42 per cent of the solid is magnesium carbonate. The addition of the sodium chloride is equivalent to raising the temperature. In some further experiments coral was employed and was shown to act very similarly to aragonite. The final conclusion is that dolomite is formed by the action of sea water on aragonite, hot and in concentrated solution. Pfaff[a] has shown that dolomite separates from solution saturated with common salt, the carbonates of lime and magnesium, and carbon dioxide, in the presence of sulphides. The sulphides are derived in nature by the action of organic materials upon sulphates.

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[a] Haidinger's Naturwiss. Abhandl., **1**, 305 (1847).

[b] Arch. Sci. Phys. et Nat., **10**, 177 (1849).

[c] Zeit. deutsch. geol. Gesell., **27**, 495 (1875).

[d] Am. Jour. Sci. (2), **28**, 170, 365 (1859); **42**, 49 (1866).

[e] Bul. Soc. Belge. Geol., **8**, 219 (1894); Tschermaks Mitt., **14**, 526 (1895).

HYDRATES OF CALCIUM CARBONATE.

Rammelsberg[b] found in a river rhomboidal crystals of $CaCO_3.5H_2O$, which at 15° C. were dehydrated even under water. Pelouze[c] has obtained the same compound by exposing a solution of lime in sugar at a temperature of 7° to 8° C. After some weeks the above compound was formed. At a lower temperature $CaCO_3.6H_2O$ was produced when carbon dioxide was passed into the solution. This same precipitate was obtained by passing carbon dioxide into lime water at 0°, the precipitate being at first flocculent but soon changing to a heavy crystalline powder. The crystals change at 30° C. to a semifluid paste, which is a mixture of anhydrous calcium carbonate and water, a result which was confirmed by Hunt.[d] At 20° C. the same change occurs, but not so rapidly, and at lower temperatures the salt effloresces. At 0° the precipitate formed by mixing solutions of calcium chloride and sodium carbonate becomes crystalline on standing. Tschiwinsky[e] considers that the existence of the hydrate $CaCo_53H_2O$ has also been established and proposes the name *trihydrocalcite.*

SOLUBILITY OF CALCIUM CARBONATE IN WATER.

The results obtained by various experimenters on the solubility of calcium carbonate in water are far from concordant. In all likelihood this may be ascribed to impurities in the calcium carbonate—as, for instance, free lime would tend to increase the apparent solubility, if the calcium in solution was determined. Another reason is probably the presence of carbon dioxide in the water used by the early experimenters. Whipple and Mayer have more recently pointed out a very important source of error which has been almost disregarded by previous workers. The solubility of the glass vessels in water is sometimes much greater than that of the calcium carbonate, and these authors have tested this point by using glass of various kinds, and have found that Bohemian glass gave alkaline solutions which would have caused errors in solubility determinations of over 100 per cent. Jena glass they have found to be much more resistant to the action of water and have used this in their determinations, in which corrections have been made for the solubility of the glass vessels.

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[a] N. Jahresb. f. Min., Beilage Bd. **9**, 485 (1894).

[b] Ber. deutsch. chem. Ges., **4**, 469 (1871).

[c] Jour. Pharm. (4), **1**, 278 (1865).

[d] Am. Jour. Sci. (2), **42**, 49 (1866).

[e] Annuaire géol. et minéral. Russie, **8**, 245 (1906).

TABLE LXI.—*Solubility of calcium carbonate in water according to various experimenters.*

$CaCO_3$ per liter.	Temperature.	Observer.
Milligrams.	°C.	
63	....	Brandes.[a]
42–63	....	Buchholz.[a]
113	(Hot)	Fresenius.[b]
94	(Cold)	Fresenius.
20	....	Péligot.[c]
78	15	Kremers.[d]
16	....	Bineau.[e]
34	....	Hofmann.[f]
36	....	Weltzien.[g]
34	....	Chevalet.[h]
13.1	16	Schloesing.[i]
28.5	....	Anderson.[j]
27	....	Lubavin.[k]
10	8.7	Hollemann.[l]
12.5	23.7	Hollemann.
103	12	Pollacci.[m]
145	100	Pollacci.
12.8	18	Le Blanc and Novotný.[n]
20.7	95 to 100	Le Blanc and Novotný.
13	20	Whipple and Mayer.[o]

[a] See Comey, Dictionary of Chemical Solubilities (1896), 82.
[b] Ann. Chem. Pharm., **59**, 177 (1846).
[c] Jour. Pharm. (3), **19**, 324 (1851).
[d] Ann. Phys. Chem., **85**, 246 (1852).
[e] Ann. Chim. Phys. (3), **51**, 290 (1857).
[f] Jour. Chem. Soc., **4**, 381 (1852).
[g] Ann. Chem., **136**, 165 (1865).
[h] Bul. mens. de la soc. chim. de Paris. Aug. 1868, p. 90; abstr. in Zeit. anal. Chem., **8**, 91 (1869).
[i] Compt. rend., **74**, 1552 (1872).
[j] Proc. Roy. Soc. Edinburgh, **16**, 319 (1889).
[k] Jour. Russ. Chem. Soc., **24**, 389 (1892); abstr. in Jour. Chem. Soc., **64 ii**, 373 (1893).
[l] Zeit. phys. Chem., **12**, 125 (1893).
[m] L'Orosi, **19**, 217 (1896); abstr. in Jour. Chem. Soc., **72 ii**, 260 (1897).
[n] Zeit. anorg. Chem., **51**, 181 (1906).
[o] Jour. Infectious Diseases, Suppl. No. 2. 151 (1906).

SOLUBILITY OF CALCIUM CARBONATE IN AQUEOUS SOLUTIONS.

Carbon dioxide.

It was shown by Vogel[a] as early as 1814 that when carbon dioxide is passed into lime water all the lime dissolves and when the solution is heated calcium carbonate precipitates. Upon the addition of carbon dioxide to the solution again the precipitate redissolves. The experiments by Irving[b] indicate that heat is evolved both when the carbonate is being precipitated from lime water and also when the excess of carbon dioxide is redissolving the precipitate. The solubility of calcium carbonate in carbon dioxide solutions has been determined by many investigators and the early results are not at all concordant. The following table contains the results obtained by the various observers:

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[a] Bul. Pharm., **6**, 258 (1814).
[b] Chem. News, **63**, 192 (1891).

TABLE LXII.—*Solubility of calcium carbonate in water carrying carbon dioxide.*

$CaCO_3$ per liter.	Temperature.	Observer.
Grams.	°C.	
0.7003	0	Lassaigne.[a]
.8803	10	Lassaigne.
.6700		Bergmann.[b]
1.800 (burnt lime)		Bischof.[c]
2.800 (pure lime)		Bischof.
2.500		Marchand.[b]
1.0 to 1.5		Struve.[b]
3.0		Caro.[b]
1.165 to 2.305		Boutron and Boudet.[d]
0.9842	12	Warington.[e]
1.13 to 1.17	15	Treadwell and Reuter.[f]
1.30 to 1.31	13.2	Treadwell and Reuter.
1.43	28	Treadwell and Reuter.

[a] Jour. Chim. Méd. (3), **4**, 312 (1848).
[b] See Caro, Inaug.-Diss., Jena (1873); Arch. Pharm. (3), **4**, 145 (1874).
[c] See Treadwell and Reuter, Zeit. anorg. Chem., **17**, 170 (1898).
[d] Jour. Pharm. (3), **26**, 16 (1854).
[e] Jour. Chem. Soc., **19**, 296 (1866).
[f] Zeit. anorg. Chem., **17**, 170 (1898).

The above results show that the solubility depends very largely upon the purity of the original material. The solubility of calcium carbonate in water containing carbon dioxide is quite similar in kind to the solubility of dicalcium phosphate in phosphoric acid. Just as the amount of dicalcium phosphate in phosphoric acid solutions increases with increasing concentrations of acid,[a] so the amount of calcium carbonate in carbon dioxide solutions increases with increasing amounts of carbon dioxide. The difference between the two cases is that in one instance the solid phase changes above certain concentrations of the acid in solution while in the case of the carbonate no carbonate other than $CaCO_3$ has been recorded. The results of Schloesing[b] on the solubility of calcium carbonate in carbonic acid solutions at 16° C. are as follows:

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[a] See Bul. No. 41, Bureau of Soils, U. S. Dept. Agr. (1907).
[b] Compt. rend., **74**, 1552 (1872).

TABLE LXIII.—*Solubility of calcium carbonate in water containing carbon dioxide at various partial pressures at 16° C.*

Pressure CO_2.	CO_2 per liter.	$CaCO_3$ per liter.
Atmosphere.	*Milligrams.*	*Milligrams.*
0.000504	60.96	74.6
.000808	72.11	85.0
.0033	123.0	137.2
.01387	218.36	223.1
.0282	310.4	296.5
.05008	408.5	360.0
.1422	....	533.0
.2538	1,072.2	663.4
.4167	1,500.5	787.5
.5533	1,846.3	885.5
7297	2,269.3	972.0
.9841	2,864.2	1,086.0

In a later paper[a] Schloesing has shown that the equation $p^m = ky$ describes the results. In the equation p is the pressure of CO_2, y is the amount of bicarbonate in solution, i. e., the amount of CaO calculated as $CaH_2(CO_3)_2$, and m and k are constants.

The empyrical formula of Schloesing has been modified by van't Hoff[b] to the form $C_1^{2.56} = KC_2$, where C_1 is the concentration of calcium bicarbonate and C_2 is the concentration of carbon dioxide, which in turn is proportional to the partial pressure of the gas. The coefficient 2.56 is known as the "activity coefficient," and is shown to vary with the dilution and at very extreme dilution equals 3. Bodländer[c] has calculated the dissociation constants at different dilutions and has recalculated Schloesing's results by a new formula, which describes the facts quite satisfactorily.

Where p is the pressure in atmospheres and y is the quantity of calcium bicarbonate in grams, the values of the constants are $m = 0.3787$ and $k = 0.9213$. Engel[d] has determined the solubility of calcium carbonate at pressures greater than 1 atmosphere and has found that the formula proposed by Schloesing describes the conditions up to 6 atmospheres, which was the highest pressure at which he worked.

TABLE LXIV.—*Solubility of calcium carbonate in water containing carbon dioxide at higher pressures.*

Pressure CO_2.	$CaCO_3$ per liter, observed.	$CaCO_3$ per liter, calculated.
Atmospheres.	*Milligrams.*	*Milligrams.*
1	1,079	1,085
2	1,403	1,411
4	1,820	1,834
6	2,109	2,139

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[a] Compt. rend., **75**, 70 (1872).

[b] Vorlesungen über theoretische und physikalische Chemie, I, 149.

[c] Zeit. phys. Chem., **35**, 23 (1900).

[d] Compt. rend., **101**, 949 (1885); Ann. Chim. Phys. (6), **13**, 344 (1888).

Treadwell and Reuter[a] have also determined the solubility of calcium carbonate in solutions of carbon dioxide at temperatures 10° to 14° C. (average 12°), with the following results:

TABLE LXV.—*Solubility of calcium carbonate in various solutions of carbon dioxide in water.*

Pressure of CO_2.	CO_2 per 100 c. c.	$CaH_2(CO_3)_2$ por 100 c. c.
Milligrams.	*Milligrams.*	*Milligrams.*
67.9	157.4	187.2
45.9	86.3	175.5
41.4	52.8	159.7
16.6	48.5	154.0
14.4	34.7	149.2
13.1	24.3	133.1
6.0	14.5	124.9
3.1	4.7	82.1
1.9	2.9	59.5
.6	....	40.2

The quantity of various samples of calcium carbonate which sea water would dissolve under various pressures has been determined by Reid.[b] In all the experiments the water contained about 1 gram of carbon dioxide per liter and the time of contact of the water and carbonate was 30 to 60 minutes.

TABLE LXVI.—*Solubility of calcium carbonate in water containing carbon dioxide.*

Material.	CO_2 per liter sea water.	Pressure.	Temperature.	$CaCO_3$ per liter.
	Grams.	*Tons.*	*°C.*	*Gram.*
Globigerina ooze I	1.0071	4	12.0	0.0906
	1.0494	4	12.0	.1486
	1.0523	4	9.0	.1191
	1.0203	4	9.0	.1080
	1.0102	(1 atm.)	12.2	.0568
	1.0744	(1 atm.)	10.0	.0572
	1.0777	2	8.3	.0999
Globigerina ooze II	1.0275	4	8.6	.0761
	1.0688	4	8.8	.0997
	1.0001	(1 atm.)	15.0	.0236
	1.0039	(1 atm.)	13.2	.0270
Coral sand I	1.0664	4	8.8	.1398
	1.0115	4	8.8	.1011
	1.0405	(1 atm.)	11.6	.0429
	1.0069	(1 atm.)	10.5	.0418
	.9666	(1 atm.)	12.2	.0407
Coral sand II	1.0596	4	9.1	.1220
	1.0738	(1 atm.)	9.0	.0391
Pteropods	1.0779	4	8.3	.1098
Crystalline	1.0557	(1 atm.)	11.0	.0516
	1.0307	4	8.3	.0371
	.9865	4	9.0	.0132
	.9845	(1 atm.)	10,0	.0102
	1.0410	....	12.2	.0082
	1.0513	....	12.2	.0050
	1.0440	....	13.1	.0034
	1.0532	....	14.7	.0048
Ground crystals	1.0536	....	12.6	.0322

The author draws the conclusion that "the amount of carbonate of lime dissolved at a pressure of 4 tons per square inch is so much greater than the amount dissolved at the ordinary pressure that I think it justifies the conclusion that the effect of pressure is to increase the rate of solution . . . . It is to be noted that, although these results may indicate that the solution of carbonate of lime in carbonic-acid water is more rapid under high pressures, it by no means follows that the solubility is *greater* than at the ordinary pressure (*ceteris paribus*)."

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[a] Zeit. anorg. Chem., 17, 170 (1898).

[b] Proc. Roy. Soc. Edinburgh, 15, 151 (1888).

Sodium hydroxide and carbonate.

In the process of manufacture of caustic alkali from alkaline carbonate and lime the relative solubility of lime and of calcium carbonate in solutions of the alkalies and alkaline carbonates is an important factor in determining the equilibrium conditions. The caustification of sodium carbonate would be represented by the reaction,

$$Na_2CO_3 + Ca(OH)_2 \rightleftarrows 2NaOH + CaCO_3.$$

This is a four-component system, water being the fourth component, and consequently when the temperature is fixed there may be five phases at some definite concentration. There may be four phases over a range of conditions, i. e., the system is univariant. Several experimenters have found the equilibrium conditions where there are the two solid phases—calcium hydroxide and calcium carbonate—liquid and vapor.

The presence of the reaction product, caustic soda, in solution depresses very greatly the solubility of calcium hydroxide, and consequently is one factor tending to bring the reaction to a standstill. Reference has already been made[a] to the results of d'Anselme on the solubility of lime in solutions of caustic soda.

As the solubility of calcium carbonate in sodium hydroxide solutions has been found to be less than in pure water, for dilute solutions of the alkali, this fact would tend to cause the reaction to go to the right, i. e., toward the formation of calcium carbonate and sodium hydroxide. The following results by Le Blanc and Novotný[b] give the solubility of calcium carbonate in these solutions:

TABLE LXVII.—*Solubility of calcium carbonate in solutions of sodium hydroxide.*

NaOH per liter.	$CaCO_3$ per liter.	
	80° C.	95° to 100° C.
Gram.	*Milligrams.*	*Milligrams.*
0.0	12.8	20.7
.004	8.7	9.6
.04	4.2	6.9
.4	4.3	5.7

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[a] Page 27.

[b] Zeit. anorg. Chem., 51, 181 (1906).

The equilibrium conditions have been found experimentally by Lunge and Schmid,[a] by Bödlander and Lucas,[b] and by Le Blanc and Novotný,[c] all of whom have shown that the change from sodium carbonate to sodium hydroxide is much more complete in dilute solutions than in concentrated solutions. For instance, the last-named authors have determined the composition of the two sodium compounds present in the solution after an excess of lime has been added to varying solutions of sodium carbonate. At 100° C., when a normal solution was used, about 99 per cent of the sodium was present as sodium hydroxide, while when a 3-normal (3N) solution was used 93.6 per cent was present as hydroxide.

A recently published paper by Wegscheider[d] contains an investigation of the nature of the solids formed when calcium carbonate is mixed with solutions of sodium carbonate. Above certain concentrations it was found that a double compound of sodium and calcium carbonate was formed, $CaCO_3.Na_2CO_3.5H_2O$ at 11° C., while at and above 40° C. the double compound was of the composition $CaCO_3.Na_2CO_3.2H_2O$. The following table gives the composition of the "constant" solutions at various temperatures, the concentration with regard to calcium carbonate being too small for determination:

Table LXVIII.—*The "constant" solutions at various temperatures in the system,* Na_2CO_3, $CaCO_3$, H_2O.

Temperture. °C.	Solid phases.	Concentration of solution.
11	$CaCO_3$; $CaCO_3.Na_2CO_3.5H_2O$	0.86 normal Na_2CO_3.
40	$CaCO_3$; $CaCO_3.Na_2CO_3.2H_2O$	2.14 normal Na_2CO_3.
60	.....do	3.77 normal Na_2CO_3.
80	.....do	4.34

The same author has also published results upon the equilibria obtaining when free caustic soda is present in the solution.

Table LXIX.—*Solid phases at different concentrations and temperatures in the system,* Na_2CO_3, $NaOH$, $CaCO_3$, H_2O.

Temperture.	Solid phases.	Concentration of solution.	
		Na_2CO_3.	NaOH.
°C.			
60	$CaCO_3$; $CaCO_3.Na_2CO_3.2H_2O$	1.8 normal	2.6 normal.
60	.....do	3.7 normal	1.3 normal.
80	.....do	1.9 normal	2.9 normal.
80	.....do	3.3 normal	2.0 normal.

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[a] Ber. deutsch. chem. Ges., **18**, 3286 (1885).

[b] Zeit. Elektrochem., **11**, 186 (1905); Zeit. angew. Chem., **18**, 1137 (1905).

[c] Loc. cit.

[d] Ann. Chem., **351**, 87 (1907).

Sodium chloride.

Lubavin[a] has recorded the following qualitative result: 100 parts of a solution of sodium chloride (2.535 per cent) dissolves 0.0037 part $CaCO_3$, calculated as CaO, or 0.0053 part calc-spar.

In the following experiments Cantoni and Goguelia[b] have determined the quantity of calcium carbonate in solutions of sodium chloride after the solution had stood in contact with solid calcium carbonate for 98 days at room temperature (12° to 18° C.).

TABLE LXX.—*Solubility of calcium carbonate in sodium chloride.*

[Time of contact, 98 days, at 12 to 18° C.]

NaCl in solution.	$CaCO_3$ per liter.
Per cent.	*Gram.*
5.85	0.0497
10.00	.0563
20.00	.0713

In the following experiments by Cameron, Bell, and Robinson[c] carbon dioxide was carefully excluded by using distilled water which had been boiled for some time before the solutions were made. This was necessary, for carbon dioxide, even at a partial vapor pressure equal to that in the ordinary air, is capable of producing a great increase in the solubility in sodium chloride solutions.

TABLE LXXI.—*Solubility of calcium carbonate in sodium chloride solutions free from carbon dioxide at 25°.*

Density $\frac{25^\circ}{25^\circ}$	NaCl in 100 grams H_2O.	$CaCO_3$ in 100 grams H_2O.
	Grams.	*Gram.*
1.0079	1.601	0.0079
1.0314	5.177	.0086
1.0466	9.25	.0094
1.0734	11.48	.0104
1.0944	16.66	.0106
1.1346	22.04	.0115
1.1794	30.50	.0119

Sodium chloride and carbon dioxide.

In the following tables are given the results of Treadwell and Reuter,[d] upon the solubility of calcium carbonate in water containing 5 grams of sodium chloride per liter and containing various quantities of carbon dioxide.

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[a] Jour. Russ. Phys. Chem. Soc., **24**, 389 (1892); abstr. in Jour. Chem. Soc., **64 ii**, 373 (1893).

[b] Bul. Soc. Chem. (3), **33**, 13 (1905).

[c] Jour. Phys. Chem., **11**, 396 (1907).

[d] Zeit. anorg. Chem., **17**, 170 (1898).

TABLE LXXII.—*Solubility of calcium carbonate in various solutions of carbon dioxide in sodium chloride solution (½ per cent).*

Pressure of CO_2.	CO_2 per 100 c. c.	$CaH_2(CO_3)_2$ per 100 c. c.
Millimeters.	*Milligrams.*	*Milligrams.*
128.8	132.5	218.4
78.2	110.1	149.2
46.1	23.5	149.2
24.0	12.5	118.3
3.8	8.7	73.9
3.4	.3	49.0

By comparison with Table LXV it is apparent that the quantity both of free carbon dioxide and of calcium bicarbonate is less in salt solution than in pure water.

The following results are quoted from the work of Cameron and Seidell[a] upon the solubility of calcium carbonate in solutions of sodium chloride, the partial pressure of carbon dioxide in the vapor phase being that of ordinary air.

TABLE LXXIII.—*Solubility of calcium carbonate in aqueous solutions of sodium chloride at 25° C. in equilibrium with atmospheric air.*

NaCl per liter.	Calcium in solution, calculated as CaH_2CO_3 per liter.
Grams.	*Gram.*
0.0	0.1046
9.72	.1770
21.01	.2051
30.30	.2152
50.62	.2252
69.37	.2212
98.4	.2172
147.4	.1971
234.5	.1569
262.3	.1227

Table LXXIV gives the results where the pressure of the vapor phase, which consisted entirely of carbon dioxide and water vapor, was one atmosphere. This was attained by saturating the solutions with carbon dioxide at a lower temperature than 25° C. and removing the stopper of the bottles at intervals to allow the excess of the gas to escape after the bottles had been brought to the temperature of the experiment.

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[a] Bul. No. 18, Division of Soils, U. S. Dept. Agr. (1901), p. 58; Jour. Phys. Chem., **6**, 50 (1902).

TABLE LXXIV.—*Solubility of calcium carbonate in sodium chloride solutions saturated with carbon dioxide at 25° C. and one atmosphere pressure.*

Density $\frac{25°}{25°}$	NaCl in 100 grams H_2O.	$CaCO_3$ in 100 grams H_2O.
	Grams.	*Gram.*
1.0129	1.45	0.150
1.0499	5.69	.160
1.0501	6.48	.173
1.0759	11.06	.174
1.1015	15.83	.172
1.1246	19.62	.159
1.1789	29.89	.123
1.1957	35.85	.103

Sodium sulphate.

The following experiments were similar to those in Table LXXI, except that sodium sulphate was used instead of sodium chloride.

TABLE LXXV.—*Solubility of calcium carbonate in sodium sulphate solutions free from carbon dioxide at 25° C.*

Density $\frac{25°}{25°}$	Na_2SO_4 in 100 grams water.	$CaCO_3$ in 100 grams H_2O.
	Grams.	*Gram.*
1.0081	0.97	0.0151
1.0161	1.65	.0180
1.0363	4.90	.0262
1.1084	12.69	.0313
1.1200	14.55	.0322
1.1539	19.38	.0346
1.1615	21.02	.0343
1.1837	23.90	.0360

Sodium sulphate and carbon dioxide.

TABLE LXXVI.—*Solubility of calcium carbonate in aqueous solutions of sodium sulphate at 24° C. in equilibrium with atmospheric air.*

Na_2SO_4 per liter.	Total calcium calculated as $CaH_2(CO_3)_2$ per liter.	Calcium actually dissolved, as $CaH_2(CO_3)_2$ per liter.
Grams.	*Gram.*	*Gram.*
0.0	0.0925	0.0925
2.800	.1488	.1488
3.235	.1729	.1729
11.73	.233	.221
36.86	.324	.302
74.01	.396	.344
116.2	.458	.366
184.2	.563	.394
213.7	.591	.406
255.9	.665	.430

In the last table the results show that the solutions contained not only the bicarbonate but the normal carbonate of calcium as well, and that with increasing quantities of sodium sulphate the quantity of calcium carbonate increased also.

Sodium chloride in the presence of gypsum as solid phase.

It will be observed by comparison of Tables LXXIII and LXXVII that the presence of calcium sulphate in solution depresses the solubility of calcium carbonate, as might be expected in the case of a salt in solution with a common ion. In both these tables the solubility of calcium carbonate passes through a maximum.

In the following table are given the results of experiments by Cameron and Seidell[a] upon the solubility of gypsum and calcium carbonate in sodium chloride solutions, both gypsum and the carbonate being present as solid phases, and the solution being in equilibrium with the atmospheric air.

TABLE LXXVII.—*Solubility of calcium carbonate in aqueous solutions of sodium chloride, in contact with solid gypsum, in equilibrium with atmospheric air.*

$CaSO_4$ per liter.	$CaH_2(CO_3)_2$ per liter.	NaCl per liter.
Grams.	*Gram.*	*Grams.*
1.9298	0.0603	0.0
2.720	.0724	3.628
3.446	.0885	11.49
5.156	.1006	39.82
6.424	.0603	79.52
5.272	.0563	121.9
4.786	.0482	193.8
4.462	.0402	267.6

Sodium chloride and sulphate.

An excess of solid calcium carbonate was added to solutions containing varying quantities of sodium chloride and sodium sulphate, and after three months at 25° C., with frequent shaking, the solutions were analyzed. Table LXXVIII gives the data obtained in this work.

TABLE LXXVIII.—*Solubility of calcium carbonate in mixed solutions of sodium chloride and sodium sulphate at 25° C.*

Density $\frac{25°}{25°}$	NaCl in—		Na_2SO_4 in—		$CaCO_3$ in 100 grams H_2O.
	100 c. c.	100 grams H_2O.	100 c. c.	100 grams H_2O.	
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Gram.*
1.2185	0.00	0.00	26.90	28.48	0.0239
1.2113	1.96	2.08	24.83	26.47	.0192
1.2115	6.43	6.93	21.67	23.36	.0137
1.2380	10.00	10.78	19.82	21.37	.0134
1.2378	10.07	10.89	19.39	20.98	.0137
1.2427	14.62	16.07	18.24	20.07	.0119
1.2570	17.16	19.18	18.43	20.74	.0116
1.2435	23.90	26.66	11.30	12.58	.0044
1.2442	27.30	31.15	8.79	10.00	.0046
1.2434	27.43	31.52	8.88	10.20	.0041
1.2270	28.32	32.17	6.74	7.65	.0043
1.2122	30.38	34.87	2.08	2.35	.0037
1.2020	31.52	35.70	0.00	0.00	.0036

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[a] Bul. No. 18, Division of Soils, U. S. Dept. Agr. (1901), p. 53.

These figures are in accord with the results of Cameron and Seidell, showing that calcium carbonate is more soluble in a saturated sodium sulphate solution than in one saturated with sodium chloride. It will be observed that as the concentration of sodium chloride in solution increases, the quantity of calcium carbonate decreases. The concentrations with respect to sodium chloride and sulphate are platted in figure 4. It has been found also that the presence of calcium carbonate in these small amounts has not appreciably affected the solubility of the more soluble chloride and sulphate of sodium.

In all these solutions calcium carbonate was the solid phase, and not a double compound. If a double compound of two calcium salts had been formed there would have been sodium carbonate in solution which would have caused the solutions to show a decided alkaline reaction. As the solutions were but very faintly, if at all, alkaline, no such change could have taken place. Further, if a double carbonate had resulted, the solution would have been rich in calcium salts and as the solution carried very little lime, it is apparent that such a change did not occur.

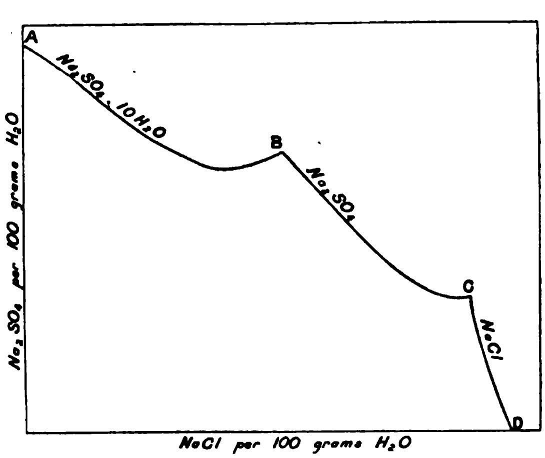

FIG. 4.—Solubility curves in the system—sodium sulphate, sodium chloride, and water at 25° C.

Owing to the very slight solubility of calcium carbonate in solutions of sodium chloride and sodium sulphate, it was expected that the presence of a salt ($CaSO_4$) with a common ion would depress this solubility even more. By the same procedure as was described in the preceding paragraph it was demonstrated that calcium carbonate underwent no change in these solutions.

TABLE LXXIX.—*Solubility of calcium sulphate and calcium carbonate in mixed solutions of sodium chloride and sodium sulphate at 25° C.*

Density $\frac{25°}{25°}$	NaCl in—		Na_2SO_4 in—		100g H_2O contains—	
	100 c. c.	100 grams H_2O.	100 c. c.	100 grams H_2O.	$CaSO_4$	$CaCO_3$
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Gram.*	*Gram.*
1.2109	2.76	2.94	23.78	25.35	0.2290	0.0163
1.2113	5.52	5.93	21.97	23.39	.1992	.0155
1.2442	28.12	32.18	8.52	9.50	.0301	.0065

Sodium chloride and sodium sulphate with carbon dioxide.

The variance of the system—sodium sulphate, sodium chloride, calcium sulphate, calcium carbonate, and water saturated with carbon dioxide—is not increased over that of the preceding system by the addition of the new component carbon dioxide, if at the same time the further condition is imposed, that the pressure of the vapor phase equals atmospheric pressure. In this case a field will represent solutions in contact with two solid phases; a boundary line, solutions in contact with three solid phases. "Constant" solutions will be in equilibrium with four solid phases.

For the experimental work on this system solutions saturated with either sodium sulphate or sodium chloride were put in contact with an excess of calcium carbonate, and the several solutions were saturated with carbon dioxide by passing the gas under pressure into the solutions at a low temperature. The bottles were then shaken at constant temperature, 25° C., and frequently unstoppered so that the pressure of the vapor phase was finally the atmospheric pressure. In all cases solid calcium sulphate, either as gypsum or a double sulphate, was found. Table LXXX gives the analytical data obtained for this system:

Table LXXX.—*Solubility of mixtures of calcium sulphate and calcium carbonate in mixed solutions of sodium chloride and sodium sulphate saturated with carbon dioxide at atmospheric pressure, at 25° C.*

Density $\frac{25°}{25°}$	NaCl in—		Na_2SO_4 in—		Calcium as calcium oxide in 100 grams H_2O.
	100 c. c.	100 grams H_2O.	100 c. c.	100 grams H_2O.	
	Grams.	*Grams.*	*Grams.*	*Grams.*	*Gram.*
1.2158	0.00	0.00	25.86	27.12	0.1430
1.2142	2.02	2.13	24.23	25.52	.1212
1.2109	4.00	4.28	22.81	24.22	.1148
1.2143	6.00	7.03	21.61	23.10	.1009
1.2248	9.98	10.77	19.53	21.09	.0812
1.2224	9.95	10.75	19.73	21.32	.0826
1.2281	11.31	12.31	19.15	20.84	.0726
1.2388	13.78	15.50	18.72	20.59	.0673
1.2590	18.67	20.40	19.80	21.61	....
1.2554	18.80	21.04	16.81	18.81	.0358
1.2332	21.46	23.81	11.61	12.88	....
1.2474	27.78	31.70	8.70	9.92	.0183
1.2429	28.47	32.73	5.56	6.26	.0291
1.2135	30.50	34.48	2.20	2.49	.0484
1.1957	31.14	35.46	0.00	0.00	.0490

In figure 5 the points A, B, C, D represent the "constant" solutions in the simple case where sodium sulphate and sodium chloride only are in solution. Upon the addition of calcium carbonate and calcium sulphate the points are displaced somewhat, the new positions being represented by A', B', C', D'. This figure has been distorted somewhat to magnify some of the differences which if drawn to scale would not be recognizable. The quantity of lime salts in solution at these points is also widely different and this has been indicated by the width of the strip $A\ B\ C\ D\ D'C'B'A'$, the points B and B' and the points *C* and *C'*, respectively, being close together. It has been found that over a certain range of concentrations, represented in the diagram by the field *B' C' F E*, gypsum is not the stable salt of calcium but a double sulphate of calcium and sodium, $3Na_2SO_4.2CaSO_4$. Thus for every field there are two stable solid phases, one of which, calcium carbonate, exists over the whole figure. The other solid phases are sodium sulphate decahydrate, anhydrous sodium sulphate, sodium chloride, double sulphate, and gypsum for the fields marked 1, 2, 3, 4, and 5, respectively.

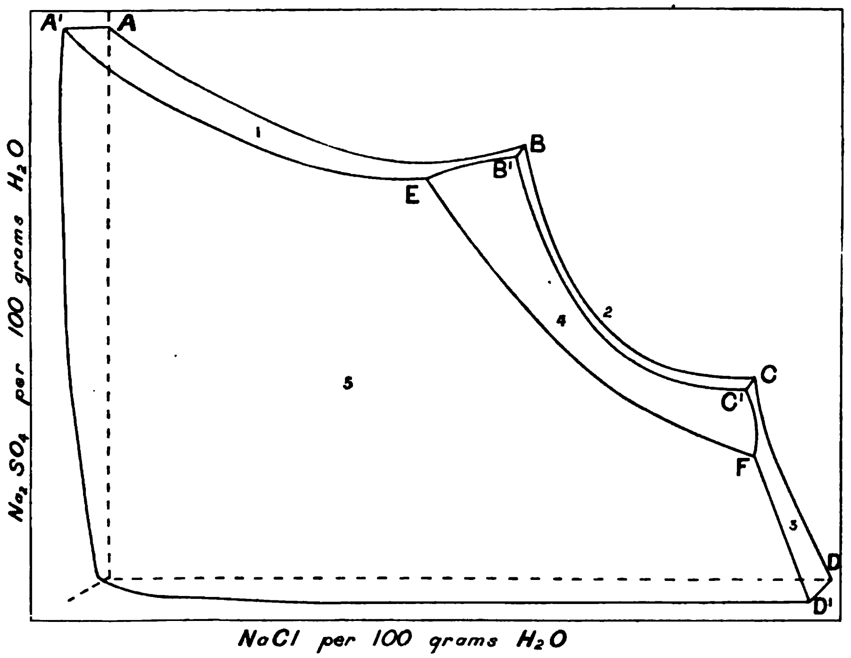

FIG. 5. —Diagram showing the solubility of calcium carbonate in solutions containing sodium chloride and sulphate, saturated with carbon dioxide at 25° C.

TABLE LXXXI.—*Data for constant solutions in the system—sodium chloride, sodium sulphate, calcium sulphate, calcium carbonate, carbon dioxide, and water at 25° C.*

Point.	Grams in 100 grams H_2O.			Solid phases.
	NaCl.	Na_2SO_4.	CaO.	
A....	0.00	27.12	0.1430	$Na_2SO_4.10H_2O$, $CaSO_4.2H_2O$, and $CaCO_3$.
E....	15.50	20.59	.0673	$Na_2SO_4.10H_2O$, $CaSO_4.2H_2O$, $CaCO_3$, and $2CaSO_4.3Na_2SO_4$.
B....	20.40	21.61	.0360	$Na_2SO_4.10H_2O$, $CaCO_3$, $2CaSO_4.3Na_2SO_4$, and Na_2SO_4.
C....	31.70	9.92	.0183	$CaCO_3$, NaCl, $2CaSO_4.3Na_2SO_4$, and Na_2SO_4.
F....	32.73	6.26	.0291	$CaCO_3$. NaCl, $2CaSO_4.3Na_2SO_4$, and $CaSO_4.2H_2O$.
D....	35.46	0.00	.0490	$CaCO_3$, NaCl, and $CaSO_4.2H_2O$.

Potassium chloride.

Cantoni and Goguelia[a] have determined the solubility of calcium carbonate in solutions of potassium chloride as follows:

Table LXXXII.—*Solubility of calcium carbonate in potassium chloride.*

[Time of contract, 98 days at 12°-18° C.]

KCl in solution.	$CaCO_3$ per liter.
Per cent.	*Gram.*
7.45	0.0748
10.0	.0742
20.0	.0828

It will be observed on comparison with Table LXX that potassium chloride has a greater solvent action on calcium carbonate than sodium chloride.

The following table contains results recently obtained in this laboratory:

Table LXXXIII.—*Solubility of calcium carbonate in aqueous solutions of potassium chloride at 25° C.*

Density $\frac{25°}{25°}$.	KCl in solution.	$CaCO_3$ in solution.
	Per cent.	*Per cent.*
1.000	0.00	0.0013
1.024	3.90	.0078
1.046	7.23	.0078
1.072	11.10	.0076
1.092	13.82	.0072
1.101	15.49	.0076
1.122	18.21	.0070
1.133	19.84	.0072
1.179	26.00	.0060

Potassium chloride and carbon dioxide.

The following table shows that the solubility of calcium carbonate in solutions of increasing content of potassium chloride passes through a maximum when the solutions are saturated with carbon dioxide:

Table LXXXIV.—*Solubility of calcium carbonate in aqueous solutions of potassium chloride saturated with carbon dioxide at atmospheric pressure at 25° C.*

KCl in solution.	$CaCO_3$ in solution.
Per cent.	*Per cent.*
3.90	0.145
7.23	.150
11.10	.166
13.82	.165
15.49	.167
18.21	.154
19.84	.140
26.00	.126

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[a] Bul. Soc. Chim. (3), 33, 13 (1905).

Potassium sulphate.

The following table contains results obtained in this laboratory on the solubility of calcium carbonate in solutions of potassium sulphate at 25° C.:

TABLE LXXXV.—*Solubility of calcium carbonate in aqueous solutions of potassium sulphate at 25° C.*

Density $\frac{25°}{25°}$	K_2SO_4 in solution.	$CaCO_3$ in solution.
	Per cent.	*Per cent.*
1.010	1.60	0.0104
1.021	3.15	.0116
1.033	4.73	.0132
1.048	6.06	.0148
1.061	7.85	.0168
1.069	8.88	.0192
1.083	10.18	.0192
1.084	10.48	.0188

Potassium sulphate and carbon dioxide.

When calcium carbonate dissolves in water carrying carbonic acid and potassium sulphate there is formed in the metathetical reaction calcium sulphate. There is enough potassium sulphate and calcium sulphate in solution to exceed the solubility of syngenite ($K_2SO_4.CaSO_4.H_2O$) and consequently above a certain concentration of potassium sulphate, syngenite is the stable solid and not calcium carbonate, all of which passes into solution. The following table gives the percentages of sulphuric acid and lime in solution for various points on the calcium carbonate and syngenite curves:

TABLE LXXXVI.—*Solubility of calcium carbonate in aqueous solutions of potassium sulphate saturated with carbon dioxide at atmospheric pressure at 25° C.*

SO_3 in solution.	CaO in solution.
Per cent.	*Per cent.*
0.0	0.062
.69	.69
1.37	.69
1.67	.47
2.18	.30
2.99	.24

Sodium and potassium salts in general.

The precipitation of calcium carbonate in the cold is retarded or prevented by solutions of the alkali salts, chloride, sulphate, nitrate, carbonate, citrate, and phosphate,[a] if the solutions are not too concentrated. According to Dulong the alkali sulphates, phosphates, phosphites, and arsenates decompose calcium carbonate on boiling.

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[a] Storer, Am. Jour. Sci. (2), **35**, 41 (1858); Dulong, Ann. Chim., **82**, 273 (1812); Spiller, Jour. Chem. Soc., **10**, 110 (1858); Kippenberger, Zeit. anorg. Chem., **6**, 177 (1894).

Sea water.

In a paper upon the action of sea water upon lime carbonate Irvine and Young[a] have included results to show that the solubility of amorphous calcium carbonate in sea water was much greater than that of crystalline calcium carbonate. One part of amorphous calcium carbonate dissolves in 1,600 parts of sea water, while 8,000 parts of sea water are required to dissolve one part of crystalline calcium carbonate.

The following table contains the results of Anderson[b] upon the relative solubilities of various forms of calcium carbonate in distilled water, in sea water, and in water saturated with carbon dioxide at 10° to 15° C.

TABLE LXXXVII.—*Solubility of carbonate of lime in distilled water, in sea water, and in solution saturated with CO_2.*

	Distilled water.		Sea water.		Water saturated with CO_2.	
	$CaCO_3$ per liter.	Time.	$CaCO_3$ per liter.	Time.	$CaCO_3$ per liter.	Time.
	Gram.	*Hours.*	*Gram.*	*Hours.*	*Gram.*	*Hours.*
Calc-spar, massive	0.0147	120	0.0075	47		
Do.			.0046	120		
Do.			.0000	396	0.0815	24
Granular					.1285	24
Fine ground					.2036	24
Impalpable powder	.0251	46	.0082	47	.4720	24
Do.			.0052	120		
Do.			.0000	396		
Coral	.0285	96	.0237	96		
Amorphous $CaCO_3$	.2480		.6100			

The table shows that upon long standing in contact with the solvent the calcium carbonate in solution decreases, indicating the formation of a less soluble modification of calcium carbonate. It is also shown that the rate at which the solid is dissolved is increased by grinding the solid to a powder.

The solubility of calcium carbonate in an artificial sea water has been determined by Cohen and Raken[c] by agitating the mixture with a current of air. After 8 days at 15° C., 53.94 milligrams $CaCO_3$ were found in one liter, and after 17 days 57.27 milligrams $CaCO_3$ per liter.

Ammonium salts.

The presence of ammonium salts tends to hold calcium carbonate in solution, even in the case of the carbonate of ammonium which might be expected to cause complete precipitation of calcium carbonate. The solubility of calcium carbonate has been shown to be increased in the presence of the chloride, carbonate, sulphate, nitrate, acetate, and succinate of ammonium.[a] Bertrand has given the amounts of different ammonium salts which are required to hold in solution 1 gram of calcium carbonate, viz, 13.98 grams ammonium chloride, 8.38 grams ammonium sulphate, and 14.44 grams ammonium nitrate, but the absolute concentrations are not given. When the solution of calcium carbonate in ammonium chloride is heated to boiling there is decomposition with the formation of ammonia and carbon dioxide.[b] The same decomposition has been shown in the case of the other ammonium salts, sulphate, sulphite, phosphate, phosphite, and oxalate.[c] On cooling the solutions of calcium carbonate in ammonium salts, the solid carbonate crystallizes out.

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[a] Proc. Roy. Soc. Edinburgh, **15**, 316 (1888).

[b] Proc. Roy. Soc. Edinburgh, **16**, 319 (1889).

[c] Proc. K. Akad. Wetensch. Amsterdam, **3**, 63 (1900); abstr. in Jour. Chem. Soc., **72 ii**, 725 (1900).

Calcium and magnesium salts.

Calcium carbonate is soluble in dilute solutions of calcium and magnesium sulphates and chlorides.[d] According to Hunt a solution containing 3 or 4 grams of magnesium sulphate per liter will dissolve over 1 gram of calcium carbonate. It is also soluble in calcium sucrate.[e]

When calcium acetate solution is added to potassium carbonate solution, the precipitate is not calcium carbonate, but a double carbonate of calcium and potassium, $CaK_2(CO_3)_2$.[f]

The action of water carrying carbon dioxide and the chloride of lime or magnesia upon various lime algæ has been investigated by Vesterberg.[g] In the presence of sodium chloride relatively more magnesia is dissolved than in the presence of calcium chloride or in the presence of magnesium chloride.

Other compounds.

Compounds which give acid solutions, such as stannic chloride and the chloride or nitrate of iron, aluminum or chromium, dissolve calcium carbonate with the evolution of carbon dioxide. As the acidity is reduced the hydroxide or oxide is precipitated. Calcium carbonate is not acted upon by concentrated nitric acid,[h] for it becomes coated with calcium nitrate, which is insoluble in the concentrated acid. Upon the addition of water, however, a brisk action begins.

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[a] Wittstein, Repert. Pharm. (2), **7**, 18 (1836); Smith, Phil. Mag. (3), **9**, 542 (1836); Brett, Phil. Mag. (3), **10**, 95 (1837); Wackenroder, Ann. Chem. Pharm., **41**, 315 (1842); Fresenius, Ann. Chem. Pharm., **59**, 117 (1846); Storer, Am. Jour. Sci. (2), **25**, 41 (1858); Bertrand, Monit. Sci. (3), **10**, 477 (1880).

[b] Demarçay, Ann. Chim. (2), **55**, 398 (1834); Schrieb, Zeit. angew. Chem., **2**, 211 (1889); Cantoni and Goguelia, Bul. Soc. Chim. (3), **31**, 282 (1904); **33**, 13 (1905).

[c] Dulong, Ann. Chim., **82**, 273 (1812).

[d] Cousté, Compt. rend., **35**, 186 (1852); Hunt, Am. Jour. Sci. (2), **26**, 109 (1858).

[e] Barreswill, Jour. Pharm. (3), **19**, 330 (1851).

[f] Reynolds, Jour. Chem. Soc., **73**, 262 (1898).

[g] Bul. Geol. Inst. Upsala, **5**, 97 (1900); **6**, 254 (1903).

[h] Barreswill, Jour. Pharm. (3), **3**, 290 (1843).

The rate at which calcium carbonate in the form of Iceland spar is dissolved by acids has been shown by Spring [a] to be independent of the chemical nature of inorganic acids whose calcium salts are soluble. It was also proved that the velocity depended upon the surface exposed, and that at low temperatures the rate was proportional to the concentration of the acid.

In solutions of hydrochloric and nitric acids in absolute ethyl alcohol, calcium carbonate is readily attacked, but not by solutions of sulphuric acid.[b] The same results have been found for solutions of these acids in the other organic solvents, acetone and methyl alcohol.[c] The addition of water to the sulphuric acid mixture causes the reaction to be very much accelerated. Acetic acid acts similarly to sulphuric acid. In all these cases the occurrence of chemical reaction depends on the solubility or insolubility of the calcium salt of the acid in the solvent employed.

GENERAL CONCLUSIONS.

1. Calcite is the stable form of calcium carbonate at ordinary temperatures. In concentrated salt solutions or at the higher concentrations, aragonite is probably the stable phase.
2. Regarding the formation of natural dolomite, the literature affords no satisfactory explanation. High temperatures and concentrated solution seem to be necessary for its formation.
3. At the low temperatures calcium carbonate forms a hydrate with five molecules of water of crystallization.
4. The results upon the solubility of calcium carbonate in water are very discordant, but there is good authority for the generalization that it is more soluble in hot water than in cold.
5. The solubility of calcium carbonate in water containing carbon dioxide increases as the quantity of carbon dioxide in solution increases.
6. The solubility of calcium carbonate is depressed by the addition of caustic soda to the solution.
7. The caustification of sodium carbonate by lime is more complete in dilute solution.
8. Calcium carbonate forms with sodium carbonate two double compounds, whose stability depends on the temperature and the concentration of the solution with which they are in contact.
9. The solubility of calcium carbonate is increased by addition of sodium chloride or of sodium sulphate.

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[a] Bul. Acad. Roy. Belg. (3), **14**, 725 (1887); Bul. Soc. Chim. (3), **3**, 177 (1890).

[b] Carette, Thesis, Lille, 1900. See Vallée, Compt. rend., **132**, 677 (1901).

[c] Vallée, Loc. cit.

10. When the pressure of carbon dioxide is one atmosphere, the solubility of calcium carbonate passes through a maximum upon increasing the concentration of sodium chloride in solution, both in the presence and absence of gypsum. When increasing quantities of sodium sulphate are added, however, the solubility of the carbonate constantly increases.

11. The solubility of calcium carbonate at 25° C. is about six times as great in a saturated solution of sodium sulphate as in a saturated solution of sodium chloride.

12. When certain solutions containing sodium sulphate and chloride are saturated with carbon dioxide in the presence of calcium carbonate a new solid phase appears, $2CaSO_4.3Na_2SO_4$.

13. When the pressure of carbon dioxide is one atmosphere, the solubility of calcium carbonate passes through a maximum upon increasing the concentration of potassium chloride or sulphate in solution.

14. In the presence of sea water the crystalline modification of calcium carbonate is more stable than the amorphous form.

15. In general the presence of ammonium salts in solution increases the solubility of calcium carbonate. On heating, carbon dioxide and ammonia escape.

16. Calcium and magnesium salts have a solvent action upon calcium carbonate.

17. Salt solutions which have an acid reaction tend to dissolve calcium carbonate.

18. Calcium carbonate is soluble in strong acids, whose lime salts are soluble in the strong acid.

MAGNESIA.

SOLUBILITY OF MAGNESIA IN WATER.

The wide variations between the results of the various observers have been attributed by Whipple and Mayer to two causes—the solvent action of carbon dioxide dissolved from the air and the action of water upon the glass vessels in which the solutions were contained. Water reacts with many kinds of glass, dissolving the bases; and as some of the determinations were made by estimating the alkalinity of the solution, this quantity of alkali dissolved from the glass walls introduced very large errors. To these two causes of discrepancy might be added a third probable source of error. The presence of very minute quantities of impurities in the magnesia, such as lime, would introduce comparatively large errors into the determinations of the solubility of magnesia. The following table gives the results of the various observers.

TABLE LXXXVIII.—*Solubility of magnesium hydroxide in water.*

$Mg(OH)_2$ per liter.	Temperature.	Observer.
Milligrams.	°C.	
250	15	Fyfe.[a]
250	15	Henry.[b]
26	(Hot and cold.)	Fresenius.[c]
5-10	(Cold.)	Bineau.[d]
9	18	Kohlrausch and Rose.[e]
8	18	Dupré and Bialas.[f]
12	22	Whipple and Mayer.[g]

[a] Cited by Henry, Jour. Pharm., **13**, 1 (1827).
[b] Jour. Pharm., **13**, 1 (1827).
[c] Ann. Chem. Pharm., **59**, 117 (1847).
[d] Compt. rend., **41**, 510 (1855).
[e] Zeit. phys. Chem., **12**, 241 (1893).
[f] Zeit. angew. Chem., **16**, 54 (1903).
[g] Jour. Infectious Diseases, Suppl. No. 2, 151 (1906).

SOLUBILITY OF MAGNESIA IN AQUEOUS SOLUTIONS.

The solubility of magnesia is given by Precht[a] as 16 milligrams per liter in water containing potash. The presence of ammonium salts increases the solubility of magnesia, even in the presence of free ammonia.[b] When warm solutions of ammonium salts are decomposed by magnesia, ammonia is evolved. Sodium and potassium salts act similarly in their solvent action on magnesia but to a far lesser degree.[c] Maigret[d] has recently investigated the solubility of magnesia in a sodium chloride solution containing sodium hydroxide and shows that the presence of the free base reduces the solubility.

TABLE LXXXIX.—*Solubility of magnesia in solutions of sodium chloride containing sodium hydroxide.*

NaCl per liter.	MgO per liter.	
	With 0.8 gram NaOH per liter.	With 4.0 grams NaOH per liter.
Grams.	*Gram.*	*Gram.*
125	0.07	0.03
140	.045	.0
160	.0	.0

The solubility of magnesia is increased by glucose.[e] Bernard and Ehrmann[f] have, however, used the insolubility of magnesia in sugar solutions as a means of separating lime and magnesia. The following table of Herz and Muhs[a] gives the solubility of magnesium hydroxide in solutions containing ammonium salts:

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[a] Zeit. anal. Chem., **18**, 439 (1879).

[b] Warington, Jour. Chem. Soc., **18**, 27 (1865); Lovén, Zeit. anorg. Chem., **11**, 404 (1896); Treadwell, Zeit. anorg. Chem., **37**, 326 (1903); Herz and Muhs, Zeit. anorg. Chem., **38**, 138 (1904).

[c] Warington, Jour. Chem. Soc., **18**, 27 (1865).

[d] Bul. Soc. Chim. (3), **33**, 631 (1905).

[e] Fleury, Jour. Pharm. (4), **28**, 400 (1878).

[f] Compt. rend., **83**, 1239 (1876).

TABLE XC.—*Solubility of magnesia in ammonium salt solutions at 29° C.*

NH_4Cl per liter.	$Mg(OH)_2$ per liter.	NH_4NO_3 per liter.	$Mg(OH)_2$ per liter.
Grams.	*Grams.*	*Grams.*	*Grams.*
4.13	1.43	6.09	1.45
5.67	1.86	14.69	2.43
9.21	2.60	....	....
13.39	3.15	....	....
20.86	4.55	....	....

When recently ignited magnesia is added to a concentrated solution of magnesium chloride a very thick mass is formed which according to Sorel[b] is composed of an oxychloride of magnesium. Bender[c] has given it the formula $MgCl_2.5MgO.17H_2O$, Davis[d] the formula $MgCl_2.5MgO.13H_2O$, and Krause[e] the formula $MgCl_2.10MgO.14H_2O$ when dried at 110°, and $MgCl_2.10MgO.18H_2O$ when air dried. André[f] has found the heat of formation of the following oxychlorides, $MgCl_2.MgO.16H_2O$, $MgCl_2.MgO.6H_2O$, $MgCl_2.10MgO.13H_2O$, and $MgCl_2.10MgO.16H_2O$. The following crystalline basic bromides of magnesium have been prepared by Tassilly,[g] $MgBr_2.3MgO.12H_2O$, $MgBr_2.3MgO.6H_2O$.

GENERAL CONCLUSIONS.

1. The various determinations of the solubility of magnesia in water are not in accord. The modern writers, however, agree that this solubility is about 10 milligrams per liter at 20° C.
2. The solubility of magnesia is augmented by various salts, including magnesium salts, but is depressed by caustic alkalies.
3. Several basic chlorides and bromides of magnesium have been recorded in the literature, and are obtained by adding magnesia to a solution of the chloride or bromide of magnesium.

MAGNESIUM CARBONATE.

MODIFICATIONS AND HYDRATES OF MAGNESIUM CARBONATE.

The mineral magnesite is probably insoluble in water[h] and is not affected by boiling with water or aqueous solutions of alkaline carbonates. Artificial magnesium carbonate has been prepared by Engel[i] by heating to 130° C. the double carbonate of magnesium and ammonium. This anhydrous magnesium carbonate "slakes" in moist air, being easily converted into the hydrated form $MgCO_3.3H_2O$. On account of its behavior when heated Davis has given it the formula $(MgOH)(HCO_3).2H_2O$, 2 molecules of water being lost when the compound is heated to 95° or 100° C., at which temperature the substance becomes constant in weight as soon as the composition $MgCO_3.H_2O$ or $(MgOH)(HCO_3)$ is reached. At 125° C. the rate of change is very much more rapid. This same change can be brought about by heating the compound $(MgOH)(HCO_3).2H_2O$ with xylene, the water which is liberated being removed as fast as it is formed and consequently hydrolysis of the salt can not ensue.

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[a] Zeit. anorg. Chem., **38**, 140 (1904).

[b] Compt. rend., **65**, 102 (1867).

[c] Ann. Chem. Pharm., **159**, 341 (1871).

[d] Chem. News, **25**, 258 (1872).

[e] Ann. Chem. Pharm., **165**, 38 (1873).

[f] Compt. rend., **94**, 444 (1882).

[g] Compt. rend., **125**, 605 (1897); Bul. Soc. Chim. (3), **17**, 964 (1897).

[h] See Davis, Jour. Soc. Chem. Ind., **25**, 788 (1906).

[i] Compt. rend., **129**, 598 (1899).

By heating the above compound with water, however, a product is obtained of widely varying composition, depending upon the time and upon the temperature. The product has been considered as a basic carbonate of magnesium. Davis, however, by a microscopical examination has proved that it is in all cases a mixture of two solid phases and not a single compound. As the dehydration of the compound $(MgOH)(HCO_3).2H_2O$ requires considerable time and as the equilibrium between the compound $(MgOH)(HCO_3)$ and the hydroxide of magnesium is reached but slowly, the solid residue was found to consist of two and often three solid phases, indicating that equilibrium had not been attained. The two reactions may be written:

$$(MgOH)(HCO_3).2H_2O = (MgOH)(HCO_3) + 2H_2O,$$
$$(MgOH)(HCO_3) = Mg(OH)_2 + CO_2.$$

The solid phases consisted of the two hydrates of magnesium carbonate and of magnesium hydroxide.

When a magnesium salt is precipitated by means of a solution of an alkaline carbonate, a basic carbonate, or a double carbonate may first be formed, but experiments by Berzelius,[a] Fritsche,[b] Favre,[c] Jacquelain,[d] and Rose[e] have proved that upon standing for several days the precipitate becomes crystalline and corresponds to the formula $MgCO_3.3H_2O$. Kippenberger[f] has ascribed the formula $MgCO_3.\frac{15}{4}H_2O$ to this compound and Marignac[g] and Damour[h] have obtained $MgCO_3.4H_2O$.

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[a] Ann. Chim. Phys. (2), **14**, 363 (1820).
[b] Ann. Phys. Chem., **37**, 304 (1836).
[c] Ann. Chim. Phys. (3), **10**, 474 (1844).
[d] Ann. Chim. Phys. (3), **32**, 195 (1851).
[e] Ann. Phys. Chem., **84**, 461 (1851).
[f] Zeit. anorg. Chem., **6**, 177 (1894).
[g] Compt. rend., **42**, 288 (1856).
[h] Compt. rend., **44**, 561 (1857).

DOUBLE CARBONATES CONTAINING MAGNESIUM CARBONATE.

When carbon dioxide is passed into a suspension of magnesia to saturation the solution contains 10.7 grams of magnesia (MgO) in one liter and when an equal volume of 95 per cent alcohol is added a precipitate of magnesium carbonate forms, $MgCO_3.3H_2O$.[a]

By mixing solutions of a soluble magnesium salt with a solution of an alkaline carbonate various compounds have been obtained:[b] $K_2CO_3.MgCO_3.4H_2O$, $KHCO_3.MgCO_3.8H_2O$, $Na_2CO_3.MgCO_3$, and $Na_2CO_3MgCO_3.15H_2O$. Kippenberger[c] has shown that the precipitate obtained by mixing sodium carbonate and magnesium sulphate in equimolecular proportions is soluble in the alkaline bicarbonates. After several hours, however, the hydrated magnesium carbonate separates in large crystals and the quantity of magnesium carbonate in solution decreases after several days. Freshly precipitated magnesium carbonate is soluble in magnesium chloride and in magnesium sulphate solutions.

The double carbonates of sodium and magnesium undergo decomposition upon heating in water, sodium carbonate passing into solution and the solid residue consisting of a mixture of magnesium hydroxide and carbonate.[d] It is difficult, however, to remove the last traces of the alkali from the solid, even by boiling, and in order to obtain pure magnesium carbonate Davis has dissolved the solid residue in water saturated with carbon dioxide and then boiled off the carbon dioxide, leaving a residue free from traces of sodium salts.

SOLUBILITY OF MAGNESIUM CARBONATE IN AQUEOUS SOLUTIONS.

Carbon dioxide.

Owing to the slow transformation of one modification into another, the solubility of magnesium carbonate in water and in aqueous solutions depends upon the source of the solid employed and on the time of contact. Engel[e] has given the results of Beckurts and of Bineau, who undoubtedly worked with widely different samples and under different conditions. One liter of water saturated with carbon dioxide dissolves 1.31 grams magnesium carbonate according to Wagner and Merckel, 8.39 grams according to Beckurts, and 23.3 grams according to Bineau. The following table gives the results of Wagner and Merckel,[f] who found the effect of increasing the quantity of carbon dioxide in solution:

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[a] Monhaupt, Chem. Zeit., **28**, 868 (1904).

[b] See Graham-Otto, Lehrbuch anorg. Chem., 5th edn., III, 730–753.

[c] Zeit. anorg. Chem., **6**, 177 (1894).

[d] Davis, loc. cit.

[e] Ann. Chim. Phys. (6), **13**, 344 (1888).

[f] Jour. prakt. Chem., **102**, 233 (1867).

TABLE XCI.—*Solubility of magnesium carbonate in water saturated with carbon dioxide at 5° C.*

Pressure.	$MgCO_3$ per liter.
Atmospheres.	*Grams.*
1	1.31
2	1.34
3	7.46
4	9.03
5	9.09
6	13.15

Engel and Ville [a] have also found that by increasing the pressure of the carbon dioxide and by decreasing the temperature the quantity of magnesium carbonate in solution increased.

TABLE XCII.—*Solubility of magnesium carbonate in water saturated with carbon dioxide at various pressures (Engel and Ville).*

T = 19.5° C.		T = 12° C.	
Pressure.	$MgCO_3$ per liter.	Pressure.	$MgCO_3$ per liter.
Atmospheres.	*Grams.*	*Atmospheres.*	*Grams.*
1	25.79	0.5	20.5
2.1	33.11	1	26.5
3.2	37.30	1.5	31.0
4.7	43.50	2	34.0
5.6	46.20	2.5	36.4
6.2	48.50	3	39.0
7.5	51.20	4	42.8
9.0	56.59	6	50.6

TABLE XCIII.—*Solubility of magnesium carbonate in water saturated with carbon dioxide at various temperatures. Pressure = 1 atmosphere (Engel and Ville).*

Temperature.	$MgCO_3$ per liter.
° C.	*Grams.*
13.4	28.45
19.5	25.79
29.3	21.95
46.0	15.7
62.0	10.35
70.0	8.1
82.0	4.9
90.0	2.4
100.0	0.0

TABLE XCIV.—*Solubility of magnesium carbonate in water saturated with carbon dioxide at various temperatures. Pressure = 1 atmosphere (Engel).*

Temperature.	$MgCO_3$ per liter.
° C.	*Grams.*
3.5	36.5
12.0	26.5
18.0	22.1
22.0	20.0
30.0	15.8
40.0	11.8
50.0	9.5

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[a] Compt. rend., **93**, 340 (1881); see also Engel, Compt. rend., **100**, 444 (1885); Ann. Chim. Phys. (6), **13**, 344 (1888).

Bodländer[a] has attempted to obtain a formula of the same form as that derived to express the solubility of calcium carbonate in water containing carbon dioxide, but has found it necessary to assume the presence of ions in solution of the form $(MgCO_3)_nMgOH$.

Finally, Treadwell and Reuter[b] have shown that at the lower concentrations there is less carbon dioxide in solution than corresponds to the formula $MgH_2(CO_3)_2$, a conclusion which has been confirmed by Rinne.[c] These results are shown in the following table:

TABLE XCV.—*Solubility of magnesium carbonate in water containing carbon dioxide at 12° to 15° C. (average, 14° C.).*

Partial pressure of CO_2.	CO_2 per 100 c.c. solution.	$MgH_2(CO_3)_2$ per 100 c.c. solution.	$MgCO_3$ per 100 c. c. solution.
Millimeters.	*Milligrams.*	*Milligrams.*	*Milligrams.*
143.3	119.0	1,210.5	....
41.6	86.6	1,210.5	....
33.8	3.5	1,210.5	....
11.7	....	1,076.6	77.3
10.3	....	762.9	76.5
8.2	....	595.2	80.7
4.7	....	366.3	70.1
4.6	....	341.7	75.8
2.5	....	263.2	74.8
1.6	....	222.9	77.1
1.1	....	216.9	71.0
0.3	....	203.6	71.1
....	....	203.3	68.5
....	....	196.0	70.2
....	....	203.6	62.5
....	....	195.4	61.6
....	....	195.4	64.1

Rinne[d] has boiled a solution of magnesium carbonate in water containing carbon dioxide for several hours, and found that the quantity of magnesia in solution constantly decreased.

Sodium chloride.

The solubility of magnesium carbonate in various aqueous solutions of sodium salts has been recorded by Cameron and Seidell.[e]

TABLE XCVI.—*Solubility of magnesium carbonate in solutions of sodium chloride free of carbon dioxide.*

Weight of liter solution.	NaCl per liter.	$MgCO_3$ per liter.
Grams.	*Grams.*	*Gram.*
996.92	0.0	0.176
1,016.82	28.0	.418
1,041.09	59.5	.527
1,070.50	106.3	.585
1,094.53	147.4	.544
1,112.48	231.1	.460
1,170.14	272.9	.393
1,199.28	331.4	.293

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[a] Zeit. phys. Chem., **35**, 23 (1900).

[b] Zeit. anorg. Chem., **17**, 170 (1898).

[c] Chem. Zeit., **31**, 125 (1907).

[d] Loc. cit.

[e] Jour. Phys. Chem., **7**, 578 (1903).

Sodium chloride and carbon dioxide.

TABLE XCVII.—*Solubility of magnesium carbonate in solutions of sodium chloride saturated with atmospheric air at 25° C.*

NaCl per liter.	Mg(HCO$_3$) per liter.
Grams.	*Grams.*
7.0	30.64
56.5	30.18
119.7	27.88
163.9	24.96
224.8	20.78
306.6	10.75

Sodium sulphate.

TABLE XCVIII.—*Solubility of magnesium carbonate in solutions of sodium sulphate free of carbon dioxide.*

24° C.			35° C.		
Weight of liter solution.	Na$_2$SO$_4$ per liter.	MgCO$_3$ per liter.	Weight per liter solution.	Na$_2$SO$_4$ per liter.	MgCO$_3$ per liter.
Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
997.52	0.0	0.216	995.15	0.32	0.131
1,021.24	25.12	.586	1,032.89	41.84	.577
1,047.60	54.76	.828	1,067.23	81.84	.753
1,080.95	95.68	1.020	1,094.77	116.56	.904
1,133.85	160.80	1.230	1,120.38	148.56	.962
1,157.34	191.90	1.280	1,151.70	186.7	1.047
1,206.03	254.60	1.338	1,179.82	224.0	1.088
1,223.91	278.50	1.338	1,196.32	247.2	1.110
1,241.99	305.10	1.388	1,236.52	299.2	1.130

GENERAL CONCLUSIONS.

1. Magnesium carbonate forms several hydrates, each of which is stable within limits of concentration and temperature.
2. Magnesium carbonate forms several double compounds with the alkali carbonates.
3. The solubility of magnesium carbonate is greatly increased by the addition of carbon dioxide to the solution, the solubility being less at the higher temperatures.
4. The solubility of magnesium carbonate passes through a maximum as the concentration of sodium chloride increases, but in the presence of carbon dioxide this solubility is depressed by addition of sodium chloride.
5. The solubility in solutions of sodium sulphate is increased by increasing the concentration of the latter.

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Issued January 31, 1908.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS—BULLETIN No. 50.
MILTON WHITNEY, Chief.

MOISTURE CONTENT AND PHYSICAL CONDITION OF SOILS.

BY

FRANK K. CAMERON AND FRANCIS E. GALLAGHER.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1908.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., September 13, 1907.

Sir: I have the honor to transmit herewith the manuscript of a technical article entitled Moisture Content and Physical Condition in Soils. In accordance with your suggestion, it has been submitted to Assistant Secretary Hays, who concurs with me in recommending it for publication.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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MOISTURE CONTENT AND PHYSICAL CONDITION OF SOILS.

INTRODUCTION.

It is generally recognized that the physical properties of a soil determining crop adaptation and growth are moisture supply, aeration, temperature, texture and structure, and "physical condition." Under these heads fall practically all physical investigations on the soil. Of course "physical condition" is by far the most important in practice, because it is the one factor directly under the control of the agriculturist, such control of the others as may be possible being usually but incidental to control of the last. Everyone who has had any experience can judge with comparative readiness as to whether a soil is in good or poor physical condition. But apparently no two observers will agree entirely as to the basis of their judgments. It is said that a soil in good physical condition must be loose, friable, loamy, have a crumb structure, work well, have a "live" look, etc., properties which are sufficiently definite to be recognized readily, but which are not susceptible of exact measurement and quantitative expression. It is evident that a comparison of soils as to their physical condition is mainly a matter of individual judgment, subject to the limitations and errors of a personal equation; and while physical condition is the most readily under practical control, paradoxical as it may seem, it is the most difficult of soil properties to study. This is because the concept or idea of "physical condition" is a summation of a number of properties rather than any one property, and because no satisfactory method of measuring this sum has yet been devised. Nevertheless, much can be done to advance our knowledge of this important subject by studies in the field and, especially, in the laboratory.

In the present bulletin are given the results of an investigation on the relation of physical condition to moisture content, in which the soils were put into different states with different amounts of water present and then subjected to various physical tests yielding measurable results. In this work the judgment of several experienced greenhouse men was available for determining the physical condition of the samples before and after the several measurements were made. It has been found that the physical condition of the soil is connected in the most intimate way with its water content. Not only is this true of its general behavior and appearance, its "workability," etc., but systematic quantitative measurements on penetrability, volume changes, apparent specific gravity, and rate of evaporation showed a direct dependence on the water content. All these properties varied regularly with regular change in the water content when the sample was in the best possible physical condition obtainable with any given water content.

One particular water content has been given special consideration. It is perfectly well known to agriculturists generally and greenhouse men especially that there is a particular water content (or perhaps a more or less narrow range of water content) differing with each soil at which plants grow best, other conditions being the same. This is popularly known as the "optimum" water content, and is supposed to be that content from which plants draw most readily their needed supply; in other words, the optimum water content is supposed to be determined by the physiological necessities of the plant rather than by the physical properties of the soil. There are difficulties, however, for which this view fails to offer sufficient and satisfactory explanation. Plants can do quite well in soils containing considerably less than the optimum water content, other conditions being favorable. That is to say, there is no decided or sharp falling off in the plant growth corresponding with a lowering of the water content until the drought limit is approached, a limit generally much below the "optimum;" and, on the other hand, there is no especial difficulty in carrying some of our common crops to a satisfactory maturity in water cultures. The investigation described in the following pages shows conclusively not only that physical condition and the several properties on which it depends have an intimate relation with the water content of the soil, but that there is marked accentuation in these properties at a critical water content; and that this critical content is identical with the optimum water content. The *moisture-penetration* curve shows a minimum force required for penetration at the optimum water content; the *moisture-apparent specific gravity* curve shows a minimum point at the optimum water content; the curves for *evaporation* show a marked difference in the rate of evaporation above and below the optimum water content. It is apparent, therefore, that the true significance of optimum water content is that particular content at which the soil can be put into the best possible condition for plant growth. The plant can then best draw its needed water from the soil because all the other factors making for good growth are also at their best. Moreover, an increase in water content in excess of the optimum generally produces a greater detrimental effect on the plant than a decrease below the optimum.

Furthermore, it should be borne in mind that practical men in bringing a soil to optimum water content judge when this point is reached by the appearance and " feel " of the soil; i. e., by the physical condition into which it can be brought, and not directly by any plant phenomenon. There is a widespread impression that the optimum water content for any one soil varies for different plants. That is, the *physiological* optimum, as determined by the plant, may not coincide with the *physical* optimum, as determined by the soil properties. While this may be true for certain exceptional cases, it is erroneous as regards the majority of common field crops, since the water content that makes for the best physical condition of the soil is as a necessary consequence the best for plant growth. Other evidence from experiments on wilting will be given in detail in support of this view. The available evidence seems to be conclusive that the problem of water supply and optimum water content is fundamentally a soil problem and incidentally a plant problem.

Another point which this investigation has brought out in a striking way is the " hysteresis " observable in the volume change when a soil is alternately wetted and dried out. This process results in a natural packing of the soil and is seriously detrimental to the maintenance of good tilth if the extremes of moisture content reached are wide apart. The causes for and mechanism of this process have been made clear by the experiments here recorded.

The importance in general farming of having a proper moisture content in the soil before plowing or other cultural operations is well known, although not always so well observed. It is regrettably common to find cases where the soil has been worked while too dry, and even more so are the cases where a soil has been worked while too wet, entailing disastrous results, requiring even years for rectification. These latter are the most baffling cases which the soil expert encounters.

The usual practice in irrigation gardening and greenhouse work of adding an excessive amount of water, so as to be on the " safe side," is far from the ideal soil management, and the working out of a better and at the same time an economical system of maintaining the water content constant, or approximately so, should be the aim of practical workers in these fields. It is believed that the data brought out in this bulletin will be of material assistance in understanding the phenomena involved in these difficult practical problems and in devising methods for the treatment and amelioration of lands which have been improperly handled.

In the course of this investigation a number of special methods and forms of apparatus were devised which it is believed will have a value not only for future investigation, but as a desirable part of the equipment of a laboratory for student work. It has been deemed well, therefore, to give quite complete and detailed descriptions, and to this end the methods and apparatus are described and illustrated in a special chapter at the end of the bulletin, and only brief references to them are given in the text describing the investigations.

PENETRATION AND COHESION.

PREVIOUS WORK.

A property of the soil of recognized agricultural importance is *cohesion*, or the force with which the soil particles cling one to another. The previous work on penetration has been usually incidental to investigations of cohesion. This property has been studied because it is a determining factor of the ease of tillage and because it gives a measure of the physical condition of the soil and its variation under different treatments. In these studies two methods have been employed. In the one the crushing strength of cylinders of soil has been taken as a measure of the binding together, or cohesion, of the soil particles; in the other the "firmness" of the soil, which is due to its cohesion, has been determined by the resistance offered to the introduction of a sharp instrument. These latter investigations have been regarded of especial value in showing the relative resistance of different types of soils to tillage and root penetration.

Volker[a] applied the penetration method to actual measurements in the field, without, however, obtaining definite results. A penetration method was used by Meyer[b] in which four pegs fastened to the corners of a square were forced a definite distance into the soil by weights placed on the square surface. The crushing method was used in an investigation by Schübler,[c] who molded damp samples of soil into rectangular prisms. The samples were then either allowed to dry in the form or were removed while still damp and dried in the air or at a high temperature. The apparatus used to determine the crushing strength of the samples consisted of a beam supported on a fulcrum about one-third the distance from one end. On the long arm of this lever was hung a scale pan to which weights could be added gradually. At the opposite end of the beam was a counterpoise that balanced the scale pan and beam. On the long arm, a short distance from the fulcrum, a blade was fastened, free to move in the vertical plane of the beam. The dried soil sample was placed under this blade and weights added to the scale pan until the soil was either cut or crushed by the knife. The weight added was taken to represent the cohesion of the soil. The highest absolute cohesion value, that for pure clay, was taken as 100 and the other measurements compared with this. The series of relative values obtained for the different soils is shown in Table I.

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[a] Neue Moglinische Annalen der Landwirtschaft, 4, 119 (1818); ref. in Puchner, Forsch. auf dem Geb. Agr.-Phys., 12, 196 (1889).

[b] Anlage zur Flora des Königreichs Hannover (Göttingen), 307 (1822).

[c] Grundsätze der Agrikulturchemie, Leipzig, 2, 74 (1838).

TABLE I.—*Cohesion of dry soils, according to Schübler.*

Soil.	Cohesion of dry soil compared to clay.	Soil.	Cohesion of dry soil compared to clay.
Pure clay (kaolin)	100.0	Humus	8.7
Clay soil	83.3	Garden soil	7.6
Fertile clay	68.6	Gypsum	7.3
Barren clay	57.3	Calcareous soil	5.0
Hofwyl soil	33.0	Calcareous sand	.0
Jura soil	22.0	Quartz sand	.0

This table shows that clay in the dry form has a relatively high cohesion, while humus and lime soils are low, and sand does not bind together at all. By comparing some of the values obtained for the above soils with their mechanical analyses it was shown that in the clay soils the presence of humus or sand greatly reduces the cohesion.

This method is of interest in showing the binding qualities of very dry soils, yet it is open to the objection that the results obtained by it do not give reliable data for soils under ordinary cultural conditions. It is rare for field soils to dry out to an extent comparable with the condition reached in this method; and it will be pointed out later that the relative values for the cohesion of different soils vary with the quantity of water present. The table shows further that the cohesion value of sand is zero, which means that in drying out the sand samples did not retain their form. If the measurements are to give a basis of comparison for the ease of working the soils in the field, such a value is of course meaningless. A method which depends on an unsupported soil column is evidently too wide a departure from field conditions.

It is apparent that measurements of soil cohesion are not of great agricultural interest unless they take into account the variable quantity of water in a soil at different times, since this quantity plays a most important rôle in determining all of its physical properties. Extensive experiments in soil cohesion taking account of this factor were made by Haberlandt,[a] in which he measured cohesion by the crushing strength of cylinders. He also divided some of his soil samples into three fractions, depending on the size of the grains, and in this way he was able to study the relation between soil cohesion and size of the particles. In the method as first used by him he molded cylinders of the soil in a glass tube one end of which was covered by a thin cloth. The cylinders and the glass tube were dipped in water to the depth of 1 centimeter and the soil allowed to take up moisture freely. The soil column, when removed from the glass tube, was 2 centimeters in diameter and 3 centimeters high. The cylinder was then allowed to dry until it had attained the desired moisture content, when the crushing strength was determined by placing a glass vessel on the top of the column and pouring in water until the soil gave way. From the weight of the vessel and water the value for the crushing strength was obtained in grams. The results for one soil are given in Table II.

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[a] Wissenschaftlich praktische Untersuchungen auf dem Gebiete des Pflanzenbaues, Wien, 1875, Vol. I, p. 22.

TABLE II.—*Moisture-cohesion relations, according to Haberlandt.*

Grade of particles.	Moisture content.	Weight required to break down soil cylinders.
	Per cent.	*Grams.*
Coarse	32.6	120
	19.8	320
	13.1	725
	7.7	290
	2.4	170
Medium	25.9	225
	19.2	265
	16.8	500
	8.1	1,115
	1.2	1,080
Fine	33.4	450
	25.8	1,150
	7.0	1,900
	4.2	2,400
	1.9	4,200

From Table II it will be seen that the strength with which the particles are held together is greatly dependent on the moisture content of the soil. In two of the samples the cohesion value reached a maximum, indicating that in these soils a certain water content was of particular significance in regard to the cohesion. The soil with the finest particles became bound together more closely as it dried out, which is in agreement with the results of other investigators.

In another experiment Haberlandt studied the effect of mixing various quantities of sand and of moor soil with the sample of soil which was used in the previous experiment. As the percentage of sand increased the resistance to crushing diminished. This was likewise true of mixtures of the same soil with the moor soil.

In a later investigation Haberlandt[a] molded cylinders of the soil in a glass tube in the same way as before, and in addition to determining the crushing strength he measured the resistance to breaking under a transverse load, by placing the soil cylinder across two parallel horizontal supports 6 centimeters apart. Midway between the supports a scale pan was suspended from the soil cylinder, and weights were added continually until the soil column gave way. The weight required was taken as a measure of the "absolute" firmness of the soil. The pieces of the broken soil column were cut down to the desired size and a measurement of the "relative" firmness was made by crushing the sample in the same manner as before described. Measurements were made on twelve different soils in which the values for "absolute" firmness varied from 115 to 3.5 and for "relatiye" firmness from 9,000 to 700. Compared by either method the soils fell in practically the same order.

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[a] Forsch. auf dem Geb. Agr.-Phys., 1, 148 (1878).

The investigation was further extended by Haberlandt to determine the change in cohesion upon the addition of small amounts of charcoal and lime. The results are given in Table III.

TABLE III.—*Effect of lime and charcoal on cohesion, according to Haberlandt.*

Mixture.	Cohesion.
	Kilograms.
Untreated soil	31.4
Soil with 1 per cent charcoal	20.0
Soil with 1 per cent lime	8.9

The cohesion was reduced 36 per cent by charcoal and 72 per cent by lime. From his various experiments Haberlandt concluded: (1) The cohesion of different soils is widely different; (2) the cohesion depends on the size of the particles; (3) the cohesion of the soil is greatly diminished by the addition of lime, and this has a great influence in determining the ease with which soils can be worked in the field; (4) at some moisture content the cohesion is least for every soil. This last conclusion Haberlandt considered of great importance as bearing upon the question of the ease of working the soil in the field.

An extensive and valuable contribution to the literature of soil cohesion and penetration was made by Puchner,[a] who obtained values for "absolute" and "relative" firmness, both by the method of penetration and by a method similar to that of Haberlandt. The apparatus by which Puchner measured the penetration of soils consisted of a vertical shaft running through a metal guide. On the lower end of the shaft was fastened a penetrating knife blade 2 centimeters broad and 1 centimeter high, the angle of the cutting edge being 13°. The upper end of the shaft carried a scale pan to which weights were added directly until the blade was forced a required depth into the soil. The unloaded shaft and scale pan were counterpoised by a weight running over a pulley. By means of a pestle the dry soil sample was packed into a dish having a perforated bottom to permit of saturation with water taken up by capillarity. This amount of water was taken to represent the total water capacity of the soil, or 100 per cent moisture content. The samples were then allowed to dry until they reached the moisture content desired, when the penetration was measured by the apparatus just described.

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[a] Forsch. auf dem Geb. Agr.-Phys., 12, 195 (1889).

The influence of changing moisture content and that of size of particles on penetration were studied. For this purpose he used quartz sand separated into seven divisions, varying from 0.01 millimeter to 2 millimeters in diameter. The cohesion of these seven samples and a sample composed of all sizes was measured with varying water content. Experiments were also made on a calcareous soil (Kalksand), which was divided into four divisions, ranging from 0.01 to 0.25 millimeter. The results of these experiments are plotted in figure 1, the weight in grams necessary to force the blade the required distance into the soil being plotted as ordinate and the moisture content in percentage of dry weight as abscissa. The same abscissas hold for both the "Kalksand" and quartz curves. The numbers on the curves represent the limiting sizes of the particles. In order further to distinguish the curves representing the composite samples, they have been drawn in dotted lines. From these curves it is readily seen that the penetration values are greater for the finer particles and that the values for the composite samples lie between the extremes.

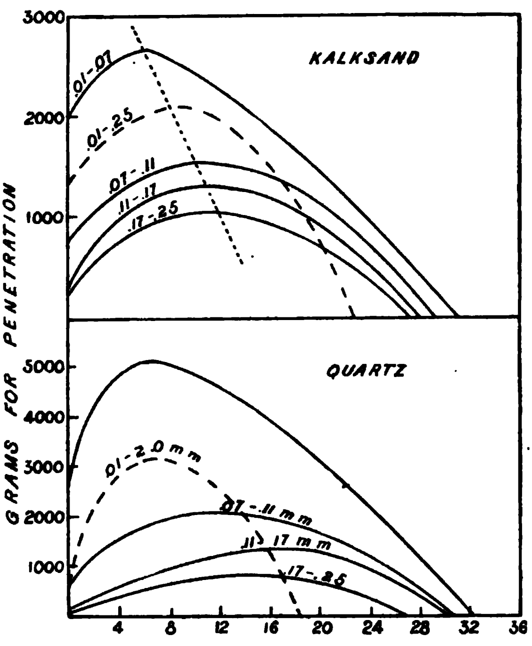

FIG. 1.—Influence of size of soil particles on penetration-moisture results for calcareous sand and for quartz, according to Puchner.

All these curves exhibit a maximum penetration value, from which it is evident that as the water content changes there is a corresponding change in at least this physical property, and that this particular water content has a special significance. As the size of particles varies the position of the maximum changes. In the case of "Kalksand" this has been indicated by drawing a straight dotted line through the maxima. In the case of the quartz curves the maxima do not seem to bear so simple a relation to each other; this may be due to the fact that the composite sample contains many large particles (2 millimeters). Although there were seven divisions for quartz, only four of the corresponding curves are shown in the figure, since the curves for the larger sizes lie too close to the axis abscissas to be conveniently plotted.

The relation of penetration to changing moisture content was studied by Puchner with certain principal soil constituents (quartz, humus, and clay), and cohesion values were obtained for the pure substances and for their mixtures. In this work the measurements were limited to one range of particles between 0.01 and 0.14 millimeter. These results have been plotted in figure 2. The curves for kaolin and quartz, humus and kaolin, and quartz and humus are drawn in separate divisions and each has its own set of ordinates.

In the case of kaolin and the mixtures in which kaolin predominates the force necessary for penetration increases steadily as the soil dries out. In the other samples the penetration curves show again a maximum point. The curves are also interesting, since the absolute values for penetration of the pure substance and of mixtures may be compared directly.

In discussing the value of cohesion measurements made on dry samples alone as indicating the physical condition of agricultural land, it was pointed out that the results so obtained were likely to be misleading, since under field conditions we seldom have to consider a dry soil. The truth of this will become apparent on examining the curves. Taking, for example, the case of humus and kaolin in the dry condition, the cohesion values vary in the different samples from about 500 to 12,000 grams. Under favorable cultural conditions the mixture "1 humus+2 kaolin" would probably contain about 35 per cent water, while "2 humus+1 kaolin" might contain from 20 to 40 per cent; the pure humus would ordinarily contain from 70 to 90 per cent. At these moisture contents, which would represent fair field conditions, the cohesion values would not be very widely different.

In his experiments Puchner made observations on many other factors relating to penetration. such as the influence of "single grain" and "crumb" structure, addition of chemicals, plant covering, frost, etc., to some of which reference will be made later. He also made quite as complete a study of soil cohesion by measuring the crushing strength of cylinders of his soil material, from which he obtained the same results and reached the same general conclusions, as follows:

(1) The cohesion of the soil, i. e., the force with which the soil particles are bound together, depends on the physical constitution of the soil, on the moisture content, and on the presence of various salts.

(2) Of the different soil constituents, clay has the greatest binding strength, while that of quartz, humus, and lime is less. The cohesion of the soil will therefore depend on the relative proportions of the different materials.

(3) The influence of water on the cohesion of soils is of great importance. In clay and clay earth the cohesion is greater as the water content diminishes, while in humus, quartz, and lime the soil particles are most strongly held together at a medium percentage of water.

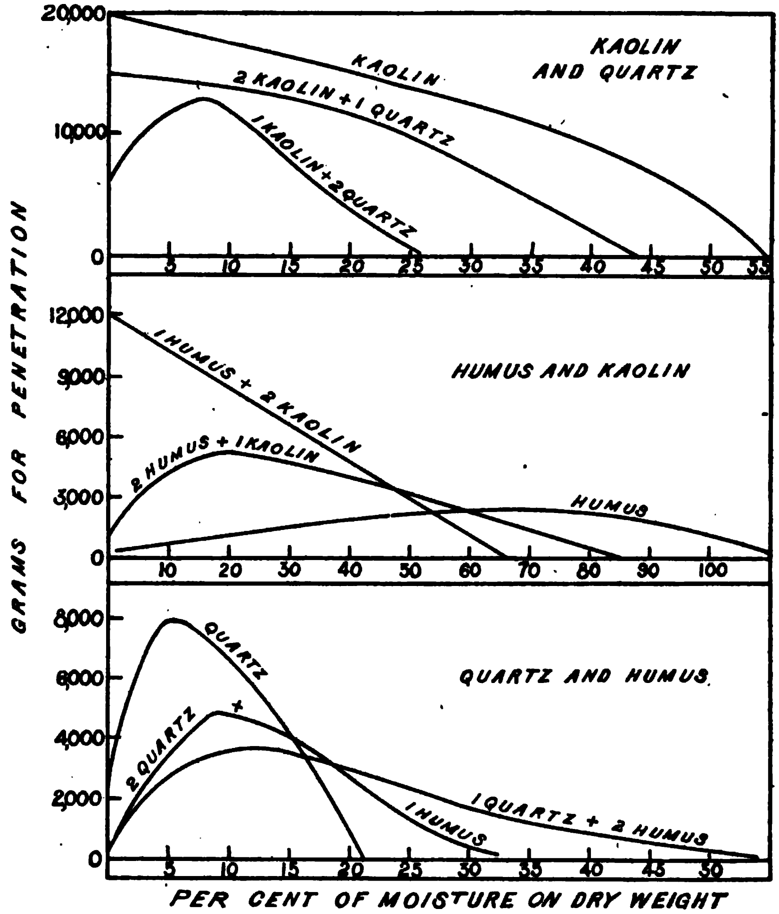

FIG. 2.—Penetration-moisture results for different soil components and mixtures of them, according to Puchner.

(4) The cohesion in any soil depends on the internal arrangement of the particles. It is greater in a "single grain" structure than in the "crumb" structure. If the soil particles are pressed together by an external force there results a proportional increase in the cohesion.

(5) Under otherwise similar conditions the binding strength of the soil is greater under crops than in fallow.

(6) The freezing of the soil greatly raises the absolute firmness.

(7) On the addition of lime the cohesion of clay is reduced under all moisture conditions, while the addition of potassium hydroxide and potassium carbonate increases the cohesion when the soil is dry, but reduces it at higher moisture content.

(8) In a consideration of the moisture condition most favorable for working a soil and best suited to placing it in most favorable mechanical condition, the question of cohesion should not enter, since with a medium water content (somewhere about 40 per cent of the total water capacity) the cohesion of most soils is at a maximum, and the soil can then be worked more easily into a crumbly condition. It is desirable to obtain the crumb structure, which is the best physical condition of the soil—i. e., the condition most favorable for crop production—even at the expense of greater labor.

It is quite evident from the work of other investigators that the cohesion or binding power is quite different for different soils and that it determines the penetrability. It is a matter of particular interest that the penetrability is closely connected also with the amount of moisture in soils. In order to investigate the influences of water on the physical condition and on the productiveness and apparent fertility of soils, a further study on penetration has been made.

RELATION OF PENETRATION TO MOISTURE CONTENT.

Object of experiments.

Unlike previous investigations in soil penetration, these measurements were not made primarily to study soil cohesion or to determine the resistance offered by various soils to cultural treatment. The purpose was rather to determine what constitutes a favorable physical condition for plant growth and how water affects this condition. It was assumed that the soil could be put into a most favorable condition as a cultural medium and that penetration measurements could be taken tentatively as an index of this state.

These considerations had an important bearing on the development of the methods used. It was pointed out by Puchner that a soil can best be put into a crumbly structure when it contains a medium amount of water. The importance of a crumb structure as a soil condition has long been known to agricultural men, and is earnestly sought in good agricultural practice. The ability of a soil to build a crumb structure or to form itself into aggregates is an important factor, determining the value of that soil as a medium for plant growth. The penetration work in previous investigations of soil cohesion has not been conducted under conditions best suited to plant growth. In fact the experimental procedure usually put the soil samples in a condition much worse than obtained in field practice. The soils were packed when dry, often with a pestle, so that the individual grains were worked into very close contact with each other, and the soils were then completely saturated with water, the samples being thus packed still closer. The desired water contents at which measurements were made were obtained by letting the saturated samples dry out. Such a procedure could hardly be said to duplicate field conditions. In order to study the influence of water upon the soil as a cultural medium it was desired to put every sample of soil into the most favorable state possible.

Experimental methods.

Neither absolute values for penetration, nor the comparison of these absolute values for different soil types were attempted; but rather the aim was to determine the variation in the penetration values for one particular soil at different moisture contents. Furthermore, a comparison of the penetration values for different soils can not be made, on account of frequent changes in the apparatus during the course of the investigation. No such variation as this, however, occurs during a set of measurements on any one soil sample, and these results are strictly comparable with one another.

In this problem one of the most serious difficulties encountered was so to control the handling of the soil sample and its packing that an agreement in results could be obtained between duplicate experiments. The difficulty in regulating the packing was rendered greater by the fact that the soils were to be examined in a loose condition, in which state even slight changes in the packing force produce large variations in the results. In studying the change of penetration with varying water content it was desired that all soil samples should have the same treatment. This it was impossible to do so long as the samples were worked by hand, and it was only possible when the process of packing was made purely mechanical. To this end a power-driven shaker (see fig. 27, p. 60) was devised, in which the soil samples were run through a coarse screen, after which they fell a definite distance through a funnel into the dish in which the penetration measurement was to be made. Since the screening was mechanical and the same in each case, the packing could be changed by varying the height through which the soil fell.

The apparatus for measuring the penetration (see fig. 30, p. 64) consisted of a long lever arm from the end of which was suspended a sharp conical tool of steel, free to swing in the vertical plane of the lever beam. This tool was forced a definite distance into the soil sample by weights added gradually to the middle of the beam. The unloaded beam and attachments were balanced by a counterweight hung beyond the fulcrum on the opposite end of the lever.

In making a penetration measurement the procedure followed was to make up a soil sample to about the desired moisture condition. The sample was run through the screening machine into the dish in which the penetration measurement was to be made. This dish was large enough so that several measurements were made on each sample, the mean of which was taken to represent the final value. The data for the complete variation of the moisture content were usually obtained by starting with air-dry soil. After the penetration value for this sample was obtained, enough water was added to the same lot of soil to increase the moisture content by a few per cent. This sample was in turn screened and measured, as before. The moisture content was thus gradually increased and measurements taken until the soil became too moist to work. The process could be reversed with equal success by letting the wet soil dry out to the desired point as long as the sample was screened at the same moisture content for which the penetration was determined. The amount of water present in the soil at each measurement was determined by drying a sample of the soil at 110° C. and calculating the moisture content to the dry weight, since this method gives moisture values which for any one soil are directly proportional to the actual amounts of water present. This method does not, however, give any idea of the moisture relations when comparison is made between different soils.

Results for Podunk fine sandy loam.

The first measurements of penetration were made for Podunk fine sandy loam, the mechanical analysis of which is given in Table IV.

TABLE IV.—*Mechanical analyses of Podunk fine sandy loam.*

Name of division.	Limits of size.	Percentage.	Name of division.	Limits of size.	Percentage.
	Millimeters.			*Millimeters.*	
Fine gravel	2.0 —1.0	0.0	Very fine sand	0.1 —.05	80.4
Coarse sand	1.0 — .5	.0	Silt	.05 —.005	18.8
Medium sand	.5 — .25	1.0	Clay	.005—.0	2.2
Fine sand	.25— .1	47.6			

This soil is seen to consist very largely of fine sand and very fine sand, along with considerable silt. It proved to be a soil particularly well adapted to an investigation of this kind, being very easy to work and not becoming sticky when water was added to it. In the air-dry condition it was found to hold about 0.3 per cent of water, and when completely saturated by letting water rise by capillarity into short columns it held about 30 per cent. The results of a series of penetration measurements on this soil are given in Table V.

TABLE V.—*Penetration-moisture relations for Podunk fine sandy loam.*

Moisture content.	Weight required for penetration.	Moisture content.	Weight required for penetration.
Per cent.	*Grams.*	*Per cent.*	*Grams.*
0.36	112	7.9	33
.92	73	10.5	38
3.9	28	13.4	42
5.8	28		

These results are shown graphically in figure 3, where the water content is measured on the axis of abscissas and the weight required for penetration on the axis of ordinates.

It can be seen from this that when the soil is put into the loosest possible condition the penetration measurements give a minimum between 4 and 6 per cent of water. This would indicate that as the moisture in the soil changes there is a definite variation in this physical property, and that one particular range of water content seems to have a special significance. It makes no difference in the result whether the water content be changed by adding water to the soil or by drying out a wet soil, for at one and the same moisture content the penetration value is a minimum.

As was pointed out in the introduction, there is a moisture condition in each soil which is recognized as the " optimum " water content, and is determined by the " feel " of the soil. To determine whether there is a relation between the critical amount of water as found in the above penetration work and this optimum water content, several samples of Podunk fine sandy loam, containing different amounts of moisture, were made up to optimum condition by practical greenhouse men. When the moisture determinations of the samples were made they were between 5 and 7 per cent of water, thus suggesting that the minimum in the penetration curve has a casual connection with the optimum water content, a quantity which up to this time has been purely arbitrary.

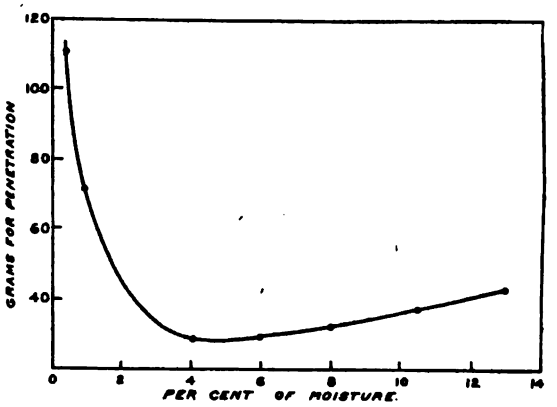

FIG. 3.—Penetration-moisture results for Podunk fine sandy loam.

Another set of penetration-moisture results, obtained in a similar manner except that the packing was somewhat greater, is given in Table VI.

TABLE VI.—*Penetration-moisture relations for Podunk fine sandy loam.*

Moisture content.	Weight required for penetration.
Per cent.	*Grams.*
0.3	178
2.6	53
6.0	48
11.6	54

These results are like the others in that they show a minimum at about 6 per cent of moisture content.

In working this soil preparatory to the measurements a great difference was noticed in its behavior as the amount of water was changed. The air-dry sample was of course in poor condition for agricultural purposes and was quite difficult to work because of the dusty nature and the compact state into which it settled. The addition of very little water produced a great change, as might have been predicted from the penetration curve; and although the soil was too dry for agricultural purposes, it was no longer dusty, seemed much lighter, and it screened and packed better. The soil sample giving the least penetration value responded most readily to working; it screened well, felt damp, light, and of an even texture. Beyond this point the soil began to feel wet and to show the effects of what might be called "free water"—i. e., water which does not seem to be an integral part of the soil. At 10 per cent water content the soil was still in fairly good condition, although it screened rather slowly, and beyond 14 per cent it could not be worked because of the difficulty of screening the wet soil. At this point it was evident that the soil was too wet for good plant growth. Although this method does not permit a study of soil condition in the neighborhood of the saturation point, it does allow sufficient variation to cover the range of soil moisture usually met under growing conditions, a range extending well above and below the optimum water content.

The penetration values according to this method form an interesting comparison with the plant growth on soils containing varying quantities of moisture. In the air-dry condition the soil is not able to sustain crops. When enough water has been added to the soil to enable it to support plant life, the penetration values drop very rapidly and are of the same order of magnitude as found at the minimum point. Beyond the minimum the penetration for Podunk fine sandy loam rises very slowly, which may be interpreted to mean that the physical condition of this soil changes but slightly over a range of several per cent, for the soil remains in very fair condition for plant growth over quite a wide range above 6 per cent of moisture.

It will be remembered that in his work on soil cohesion Puchner obtained maxima in his penetration-moisture curves, while the results just described showed minima. Puchner attributed his maximum values to an increase in the soil cohesion due to the presence of a definite amount of water in the soils. He also pointed out that this particular amount of water in the soil was most favorable for the formation of floccules or soil aggregates and the attainment of a crumb structure, due to this same increased cohesion. This appears to connect his observations with those here recorded and to show that the same forces which caused a maximum under the one method of procedure operated under a very different method to give a minimum. In order to test this point, a penetration-moisture study was made on Podunk fine sandy loam under conditions similar to those of the Puchner method. The results obtained are given in Table VII and graphically represented in figure 4. In order to make this result more easily comparable with other penetration results, we have included in the figure, using the same abscissas, a curve obtained for the same soil by the regular method of loose packing. Each curve, however, is given with its own ordinates. Although the penetration value for the critical point exhibited by the maximum is over one hundred times as large as the value given by the penetration at the minimum, and although the methods are widely different and represent very different conditions of internal arrangement of the soil particles, the agreement of the critical points in regard to the water content of the soils is very striking indeed. From this it is evident that in a soil some particular water content is of marked importance in determining the physical character of the soil, which property is undoubtedly determined by the distribution of the water.

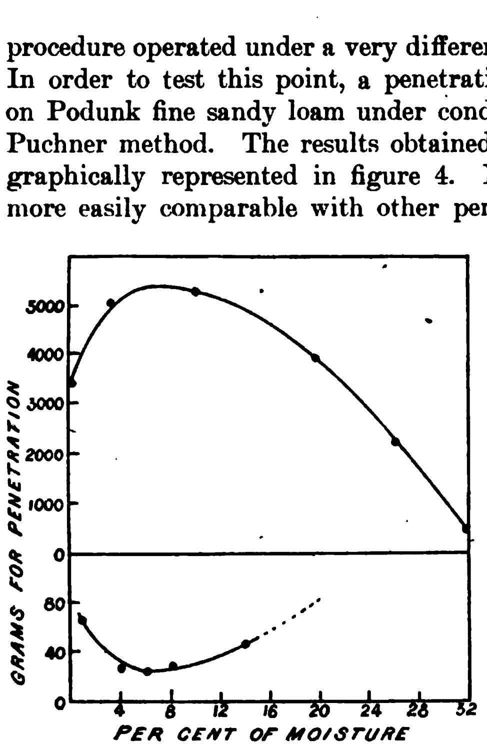

FIG. 4.—Penetration-moisture results for Podunk fine sandy loam by method of Puchner and by method of loose packing.

TABLE VII.—*Penetration-moisture relations for Podunk fine sandy loam, by the Puchner method.*

Quantity of water in soil.		Weight required for penetration.
Proportion of dry weight.	Proportion of total water capacity.	
Per cent.	*Per cent.*	*Grams.*
32.0	100.0	532
26.0	81.0	2,320
19.4	60.8	4,080
8.6	26.8	5,300
2.7	8.5	5,052
.0	.0	3,400

At the same time some experiments were made on the variation in the penetration-moisture relations when the soils were packed under different pressures. These results have a special interest in connection with the forms of the curves obtained by Puchner's method and by our method. In studying the effect of packing the soil, samples of Podunk fine sandy loam were prepared in the regular manner of loose packing, except that before the penetration measurement was made the desired pressure was applied to the surface of the soil by means of an apparatus designed for that purpose (see p. 62). The results of these measurements are given in Table VIII, and shown graphically in figure 5. The amount of the pressure per square centimeter used in packing the soil is given on each curve.

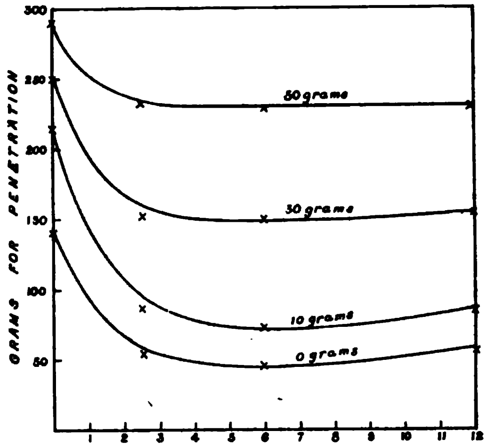

FIG. 5.—Penetration-moisture results with different packings.

TABLE VIII.—*Penetration-moisture relations for Podunk fine sandy loam, packed under different pressures.*

Packing force per square centimeter.	Moisture content.	Weight required for penetration.	Packing force per square centimeter.	Moisture content	Weight required for penetration.
	Per cent.	*Grams.*		*Per cent.*	*Grams.*
0 gram	0.0	178	30 grams	0.0	250
	2.6	58		2.6	156
	6.0	48		6.0	150
	12.2	54		12.2	154
10 grams	.0	237	50 grams	.0	291
	2.6	84		2.6	282
	6.0	72		6.0	230
	12.2	82		12.2	230

Although the pressures applied are not large and do not raise the penetration values anywhere near the point reached by samples measured according to Puchner's method, yet there is a well-defined tendency for the curves to flatten out as more pressure is applied. There is much less difference between the penetration values of the minimum and the dry state in the sample packed under 50 grams than there is in the sample packed under 10 grams pressure. The difference in the results obtained in the two penetration methods discussed is obviously one of packing. It would seem that upon increasing the pressure used in packing the loose samples a series of curves would be obtained ranging from those by our method, showing a minimum, to those by the Puchner method, showing a maximum. It was not deemed advisable at the present time to investigate this point further.

Results for Miami black clay loam.

Having found the above results for a sandy soil of low water capacity and poor in organic matter, the same method of study was applied to the Miami black clay loam, a soil of widely different character, a silty soil rich in organic matter, having a large capacity for water. The mechanical analysis of this soil is given in Table IX.

TABLE IX.—*Mechanical analysis of Miami black clay loam.*

Name of division.	Limits of size.	Percentage.	Name of division.	Limits of size.	Percentage.
	Millimeters.			*Millimeters.*	
Fine gravel	2.0 -1.0	1.2	Very fine sand	0.1 -0.05	6.2
Coarse sand	1.0 - .5	7.6	Silt	.05 - .005	53.4
Medium sand	.5 - .25	3.9	Clay	.005- .0	11.6
Fine sand	.25- .1	16.1			

The total water capacity of this soil is about 60 per cent, and in the air-dry condition it ordinarily contains about 8 per cent of moisture. When this soil was made up to optimum water content by field methods it was found to contain from 35 to 40 per cent of water.

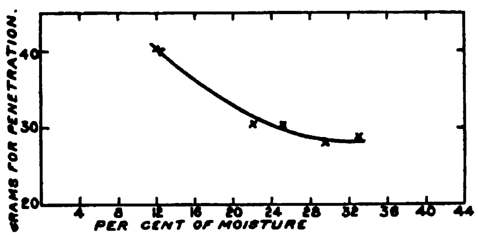

FIG. 6.—Penetration-moisture results for Miami black clay loam.

A penetration-moisture curve was made for Miami black clay loam when the soil was put each time into the loosest possible condition, the method being the same as already described for Podunk fine sandy loam. The results are shown graphically in figure 6.

When water was added to a comparatively dry sample the penetration value dropped to a minimum at 32 per cent moisture content. Enough water was added to the 32 per cent sample to increase the water content by several per cent, whereupon the soil proved too sticky to screen well. At 32 per cent the soil was in excellent condition, but on account of its clayey nature a few per cent of water caused a great change in the "workability." From this curve it is evident that as water is added to the dry soil, the cohesion is increased and the soil can be worked into aggregates. When the cohesion of the soil is greatest, as evidenced by a minimum in the penetration curve, the soil is in excellent physical condition.

Results for Leonardtown loam.

The next soil studied was quite different from those previously described, being a light-colored soil containing considerable clay and little organic matter, becoming rather sticky when wet, and on drying setting in a hard condition. The optimum water content for this soil was found to lie at about 15 per cent, a value midway between the optimum water content of the Podunk fine sandy loam and that of the Miami black clay loam. In the air-dry condition the soil contains about 1.3 per cent of water and when saturated holds some 34 per cent Several concordant sets of penetration results were obtained for this soil. Despite its tendency to become sticky when wet, it was possible to carry the penetration curve some distance beyond the optimum water content. Table X and figure 7 show the results of one set of measurements. The curve drops to a well-defined minimum at about 15 per cent of moisture, which is also the optimum water content.

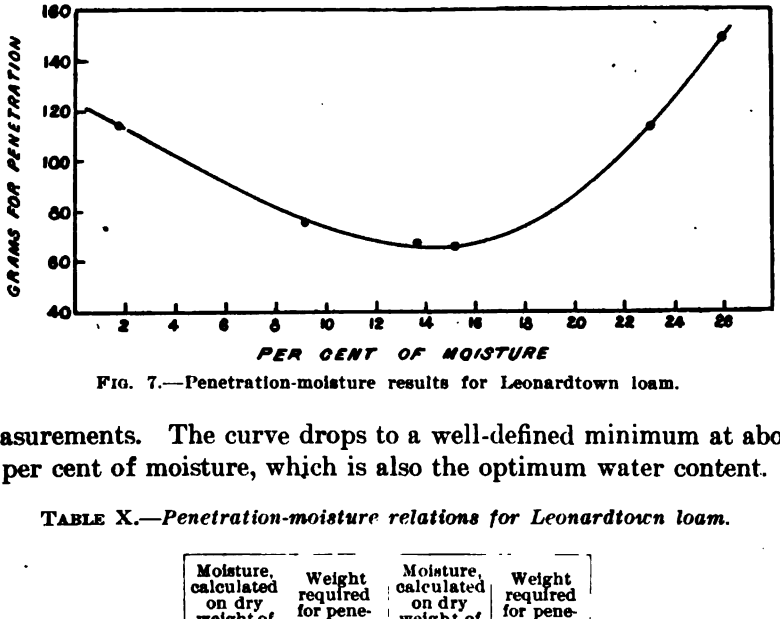

FIG. 7.—Penetration-moisture results for Leonardtown loam.

TABLE X.—*Penetration-moisture relations for Leonardtown loam.*

Moisture, calculated on dry weight of soil.	Weight required for penetration.	Moisture, calculated on dry weight of soil.	Weight required for penetration.
Per cent.	*Grams.*	*Per cent.*	*Grams.*
1.7	115	15.2	66
9.1	75	23.1	115
13.7	68	25.9	150

It was pointed out in the case of Podunk fine sandy loam that the form of the penetration curve might serve as an index to the character of the soil, and that for several per cent beyond the optimum water content the penetration curve rose very slowly, indicating that the physical properties change slowly and that the soil remains in fairly good agricultural condition. The penetration curve for

Leonardtown loam rises sharply, indicating a more marked change in the physical condition of the soil. Here also the curve corresponds to the field observations, for the favorable soil condition existing at 15 per cent of water rapidly disappears with a slight increase of water content. Further data on penetration for this soil are given in Tables XXIII and XXIV.

Results for Muck.

The next soil was studied as a check upon the conclusions reached in the previous work because it is an extreme soil type, being composed largely of organic matter and having a high water content. The mechanical analysis of this soil is not presented, as it would give little indication of the soil texture owing to the large quantity of organic matter present. In the air dry condition this soil ordinarily holds about 45 per cent of water, and when saturated some 220 per cent. The soil is in good condition for agricultural purposes over quite a wide range of moisture content, and it would be difficult to assign a close limit for the optimum water content as determined by the ordinary field method; however, it may be considered as between 120 and 140 per cent. The penetration measurements were made in the usual manner, the results being given in figure 8. From this it is seen that the penetration value reaches a minimum at about 120 per cent of moisture, which agrees well with the optimum water content.

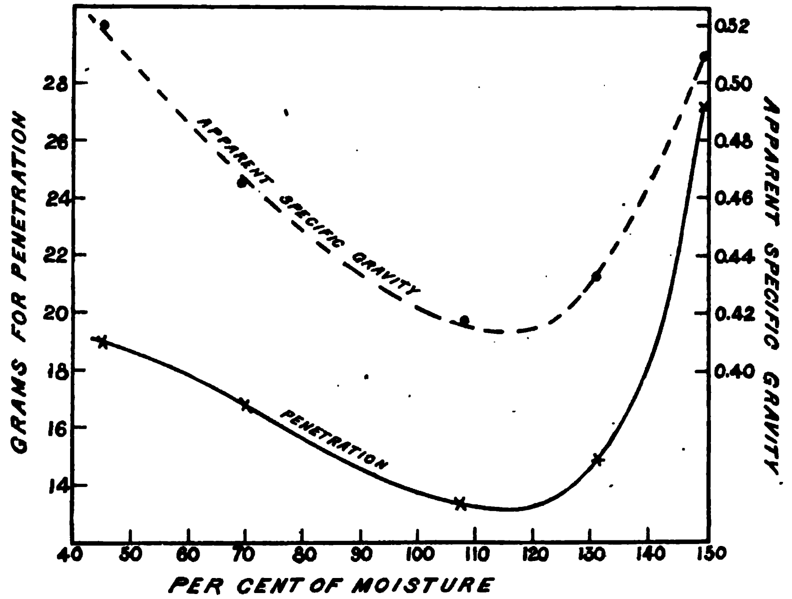

FIG. 8.—Penetration-moisture and apparent-specific-gravity-moisture results for Muck.

APPARENT SPECIFIC GRAVITY OR VOLUME.

PREVIOUS WORK.

In 1838 Schübler[a] studied the volume changes of soil by drying out wet samples until the weight no longer decreased. Representing the original volume as 1,000, he gives the volume to which the soils contracted on drying. In this way a comparison was obtained between different soil types. The results are shown in Table XI.

TABLE XI.—*Volume changes of soils on drying, according to Schübler.*

Material.	Percentage of original volume.	Material.	Percentage of original volume.
Quartz sand	100.0	Clay	88.6
Calcareous sand	100.0	Ordinary field soil	88.0
Gypsum	100.0	Fertile garden soil	85.1
Slate marl	96.5	Magnesium carbonate	84.6
Calcium carbonate	95.0	Kaolin	81.7
Potters clay	94.0	Humus	80.0
Clay loam	91.1		

The diminution of volume on drying was determined for six soils by Wolff,[b] who measured the change by means of a graduated cylinder. The influence of the size of the particles on the volume changes in soil was first studied by Haberlandt.[c] He used twelve soil samples, each of which was divided mechanically into ten separations. From the change in volume of the different soils and the water capacity, humus content, and mechanical analysis, conclusions were reached regarding the influence of different soil constituents on the volume changes. The experimental method consisted in measuring the change in volume of soil cylinders made from the damp earth. Haberlandt came to the following conclusions:

(1) The volume change which different closely packed soils undergo in drying out from a wet condition varies from 0 to 30 per cent of the original volume.

(2) Such volume changes are measured best in closely packed soils; loose soils are not well suited to measurement.

(3) Of the soil constituents humus has the most influence on volume change.

(4) It is probable that the volume changes of soils bear a linear relation to the fineness of the particles; yet this is only the case when these fine particles all have the same power to swell.

The volume changes due both to drying out and wetting were studied by von Schwarz.[d] He used four soil samples the mechanical analyses of which are given in Table XII. The volume changes are given in Table XIII.

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[a] Grundsätze der Agrikultur-Chemie, Leipzig, II, 82 (1839).

[b] Anleitung zur chemischen Untersuchung landwirtschaftlich wichtiger Stoffe, Berlin, 1899.

[c] Fühling's landw. Ztg., 7, 481 (1877).

[d] Erster Bericht über Arbeiten der k. k. landwirtschaftlichen Vers.-Stat. in Wein (1870–1877), p. 51.

TABLE XII.—*Mechanical analyses of soils used in volume studies by von Schwarz.*

Soil type.	Sands.				Suspended material.
	Coarse.	Medium.	Fine.	Very fine.	
	Per cent.	*Per cent.*	*Per cent*	*Per cent.*	*Per cent.*
1. Sand	0.0	96.34	3.11	0.55	0.55
2. Loam	0.0	19.87	31.70	30.89	18.04
3. Clay	0.0	0.0	0.0	4.53	95.47
4. Moor	Contained 82.6 per cent organic matter.				

TABLE XIII.—*Volume changes of soils on drying, according to Von Schwarz.*

Soil.	Decrease on drying.	Increase on wetting.
	Per cent.	*Per cent.*
1. Sand	0.0	0.0
2. Loam	17.0	19.2
3. Clay	29.8	42.4
4. Moor	60.2	....

An extended study of the volume changes on wetting and drying soils was made by Wollny.[a] In the apparatus devised by him for this study the soil samples were contained in a wide cup with a perforated bottom. This was surrounded by an outside dish so that the samples could be wetted by capillary water. On the surface of the soil rested a metal plate to which an upright rod was fastened. The weight of the rod and plate was counterbalanced by a weight running over a pulley. The upper part of the rod was notched so that it constituted a part of a rack and pinion that, on moving, revolved a pointer on a circular scale. The soil to be measured was packed into the containing dish in the dry state, the surface leveled, and the plate which moved the measuring mechanism was adjusted to the surface. By allowing the wet soil to dry, another measurement could be made. A measurement of the relation of volume change to size of particles on drying a soil gave the results in Table XIV.

TABLE XIV.—*Volume changes on drying soil separates, according to Wollny.*

Soil (quartz sand).	Size of particles.	Decrease in volume due to drying.
	Millimeter.	*Per cent.*
I	0.01-0.07	0.99
II	.07- .01	.17
III	.11- .17	.15
IV	.17- .25	.11
V	.25- .50	.0

From this table it follows that the change of volume in quartz sand is greatest for the finest material. Similar results were obtained when the dry soil samples were wet, although in this case the volume changes were greater, as can be seen from Table XV.

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[a] Forsch. auf dem Geb. Agr.-Phys., 20, 1 (1897).

TABLE XV.—*Volume changes on wetting soil separates, according to Wollny.*

Soil (quartz sand).	Size of particles.	Increase in volume due to wetting.
	Millimeter.	*Per cent.*
I	0.01–0.07	8.01
II	.07– .11	5.09
III	.11– .17	1.25
IV	.17– .25	.78
V	.25– .50	.0

Measurements were made on drying and wetting the principal soil constituents—quartz, clay, and humus, and their mixtures. The quartz used in this work was the finest size, varying from 0.01 to 0.07 millimeter. Table XVI gives the values obtained both in drying and wetting the samples.

TABLE XVI.—*Volume changes of different soil constituents and their mixtures due to changing moisture content, according to Wollny.*

Soil mixture.	Decrease on drying.	Increase on wetting.
	Per cent.	*Per cent.*
Kaolin	39.92	36.92
Kaolin, 2 parts + quartz, 1 part	33.17	30.90
Kaolin, 1 part + quartz, 2 parts	20.63	19.28
Quartz	.99	8.01
Quartz, 2 parts + humus, 1 part	2.86	10.84
Quartz, 1 part + humus, 2 parts	4.58	14.07
Humus	5.39	15.92
Humus, 2 parts + kaolin, 1 part	23.63	25.22
Humus, 1 part + kaolin, 2 parts	35.19	32.79

From this it is to be concluded that the volume changes in a soil are greater the more clay there is present and less the greater the amount of quartz. The humus causes an increase in the volume change when mixed with quartz, but has an opposite influence in mixtures of clay.

A number of other factors that influence volume changes in soils were studied by Wollny, such as effects of hydrates and salts, the effect of the arrangement of the soil particles, and the effects of rainfall and freezing, to some of which further reference will be made in the following pages.

RELATION OF VOLUME TO MOISTURE CONTENT.

Object of experiments.

From the work on volume changes just reviewed it is evident that variations in volume of greater or less magnitude occur in all soils when wetted and dried, which changes are influenced by a number of factors. The relation between the magnitude of these changes had been well established for a number of soils and under a number of different conditions. In none of the work, however, is there any reference to the variation in volume with the variation in moisture content. What has been measured may be designated the "total" change, which represents the difference in volume between the saturated and the air-dry conditions. Whether all or the greater part of the variation occurs over the range of low percentage of water or near the saturation point, or whether it is equally distributed over the entire range of moisture variation, has not been determined. In studying the effect of different amounts of water as affecting the physical state of the soil and determining favorable conditions for plants, it is of particular interest to know whether special quantities of water have a determining influence on the physical properties.

Variations in water content have all been in one direction, from the wet to the dry state, since there is no satisfactory way of adding regular intermediate percentages of water to a soil and leaving it in place for measurement. A soil could of course be molded into any convenient shape, saturated with water and measurements on the volume of the sample made as the water content decreased, without in any way disturbing the soil sample. The parallel results obtained by Wollny in the measurement of the "total" volume change in wetting and drying out a sample, indicate that the determinations in drying out a sample will probably give a true idea of the nature of the changes occurring.

Experimental methods.

Several different methods were used to measure the change in volume, because it was desired to have check methods and because different soil samples did not lend themselves equally well to the same method. The contraction along one dimension was measured rather than the actual volume change. The assumption was made that the contraction was the same in all directions and from the linear change for unit length the percentage volume decrease was calculated from the formula $D=1-(1-x)^3$, where x represents the unit linear change.

In one method, which will be designated the "soil column method,"[a] a cylinder of soil was supported in an inclined position on a metal form made by sawing a brass tube in half, longitudinally. A cylindrical brass follower was brought in contact with the upper end of the soil column. As the wet soil column dried out and diminished in length the brass follower moved downward, and this movement was measured by means of a micrometer screw, reading to 0.001 centimeter.

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[a] For full description see p. 67 and fig. 32.

This same micrometer was used at a different time to measure the contraction of samples contained in vertical glass tubes (see p. 65 and fig. 31) where a follower was also used in connection with the soil surface. This method will be designated as the "glass-tube method."

A different micrometer screw, reading to 0.0001 centimeter, was used in another method, where the soil sample was held in a cylindrical dish (see p. 68 and fig. 33), through the perforated bottom of which the sample could be saturated with water. A brass disk was set on the surface of the soil and the micrometer point brought in contact with this. For convenience this method will be designated the "micrometer method." A cathetometer was used to follow the contraction in soil samples supported in containing vessels having perforated bottoms. The point of an upright shaft, supported by a disk resting on the surface of the soil, was focused on the cross lines of the cathetometer telescope and thus the variation in the height of the soil surface was followed. This method will be called the "cathetometer method."

As a further indication of volume changes the apparent specific gravity of the soil was measured by weighing a unit volume in the condition in which it was worked. These observations were made at the same time that the penetration work was being carried on. In determining these data for the various soil samples it was necessary to level off the dish carefully, weigh dish and soil, and divide the weight of the soil by the volume of the dish.

Results for Podunk fine sandy loam.

It has been shown above that at a certain percentage of water the penetration results indicate that it is possible to work the soil into a maximum "looseness," which amount of water corresponds to the optimum water content. This observation was further checked by measuring the apparent specific gravity of the soil—the results being given in Table XVII.

TABLE XVII.—*Apparent specific gravity-moisture relations for Podunk fine sandy loam.*

Moisture content.	Apparent specific gravity.	Moisture content.	Apparent specific gravity.
Per cent.		*Per cent.*	
0.36	1.31	7.9	0.665
.92	1.21	10.5	.722
3.9	.69	13.4	.777
5.8	.655		

These data are better illustrated by the curve in figure 9, from which it is seen that the variation of apparent specific gravity with moisture content corresponds closely with the penetration-moisture results. On account of the greater accuracy attainable by weighing, the data given by the apparent specific gravity variations are even more concordant than those given by penetration measurements, which are more difficult to make with accuracy on account of the influence of small irregularities in packing.

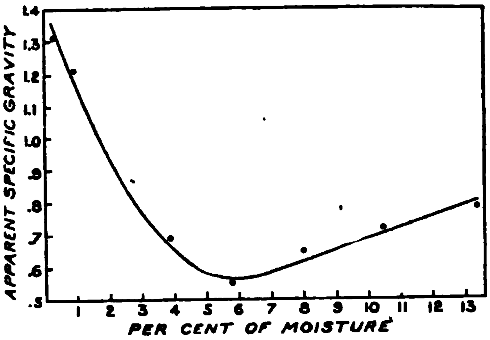

FIG. 9.—Apparent-specific-gravity-moisture results for Podunk fine sandy loam.

The apparent-specific-gravity data obtained in connection with the penetration measurements made when the soil was subjected to different packing pressures are shown by means of the curves in figure 10,

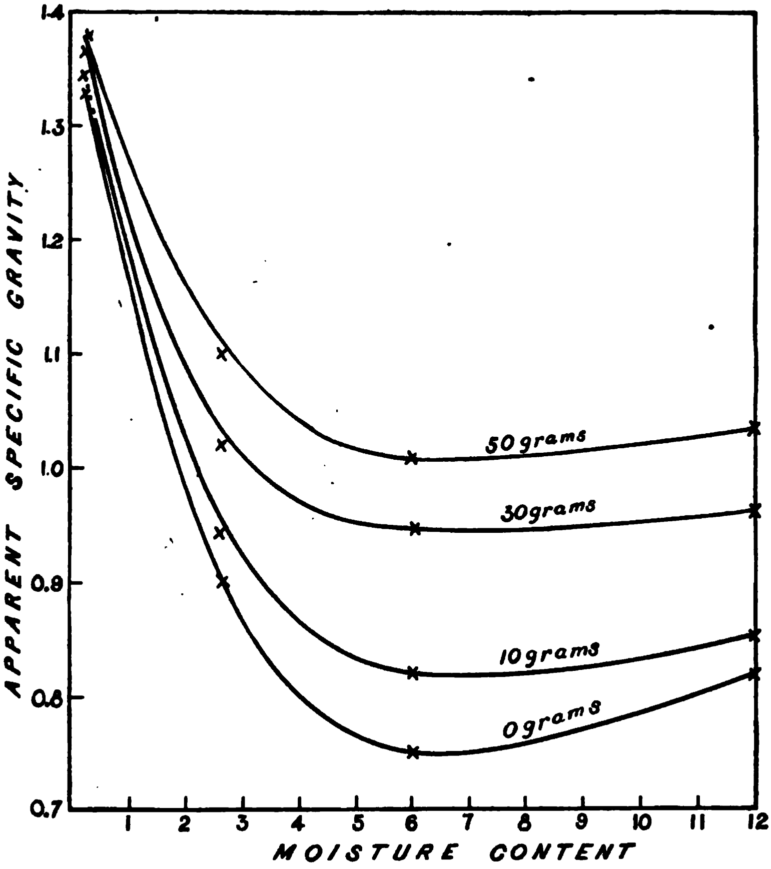

FIG. 10.—Apparent-specific-gravity-moisture results for Podunk fine sandy loam with different packings.

where the numbers on the curves represent the packing force per square centimeter. These curves are similar to the corresponding penetration curves, but they indicate more clearly the tendency to flatten out under increasing pressure due to the fact that the specific gravities of the dry samples are much closer together, so that the results of packing the loose soils at the optimum water content are more marked.

It can be readily seen from the work of Wollny on the "total" change of volume of soils that the measurement of the change of volume in sand with varying moisture content would present exceptional difficulties on account of the very small change of volume. When it is borne in mind that the volume is a cubical function of one length, the difficulty of obtaining accurate measurements on the linear contraction can be appreciated. In comparison with the readiness with which contraction measurements were made on some soils, the study of the volume change in Podunk fine sandy loam presented serious experimental difficulties. But these results were essential in order to compare the variations in this physical property with the changes in penetration and apparent specific gravity already given, and to complete a correlation of the individual properties that are dependent on the moisture content of the soil.

The results of a series of measurements on the volume changes in Podunk fine sandy loam as made by the micrometer method are given in Table XVIII.

TABLE XVIII.—*Volume-moisture relation for Podunk fine sandy loam.*

Moisture content.	Linear decrease.	Volume decrease.	Moisture content.	Linear decrease.	Volume decrease.
Per cent.	*Centimeter.*	*Per cent.*	*Per cent.*	*Centimeter.*	*Per cent.*
32.9	0.0	0.0	11.5	0.022	7.13
29.8	.006	1.98	9.7	.022	7.13
29.0	.007	2.19	8.2	.022	7.13
27.7	.011	3.6	6.8	.022	7.13
22.7	.021	6.87	6.4	.0225	7.13
18.3	.022	7.13	5.4	.0255	8.36
16.0	.022	7.13	3.7	.0255	8.36
12.2	.022	7.13	2.0	.026	8.40

From the table it will be seen that the saturation point at which the measurements were started was about 33 per cent moisture content. As the sample dried out there was a gradual decrease in volume until about 18 per cent of water was reached when the contraction had amounted to 7.13 per cent of the original volume. From this point on there was very little, if any, contraction in volume over many per cent decrease in moisture content. When the soil reached about 6 per cent moisture content, however, a more rapid volume decrease commenced. At 2 per cent of water the volume decrease had reached

8.4 per cent of the original volume. These data are shown in another form in figure 11, where the moisture content is platted as abscissa and the per cent volume decrease as ordinate.

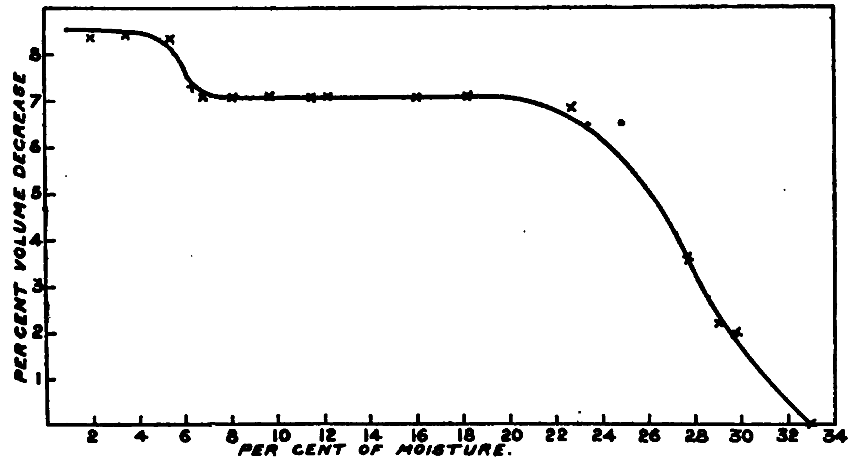

FIG. 11.—Volume-moisture results for Podunk fine sandy loam by the micrometer method.

In Table XIX and figure 12 is given a series of measurements made by the "glass-tube method," and these show the same variations as do the previous measurements.

TABLE XIX.—*Volume-moisture relations for Podunk fine sandy loam.*

[Length of soil column, 10 centimeters.]

Moisture.	Linear decrease.	Volume decrease.	Moisture.	Linear decrease.	Volume decrease.
Per cent.	*Centimeter.*	*Per cent.*	*Per cent.*	*Centimeter.*	*Per cent.*
23.8	0.0	0.0	5.9	0.023	0.69
17.7	.015	.48	3.0	.043	1.80
9.3	.016	.50	1.6	.048	1.90
7.4	.016	.50			

The total percentage decreases are not the same by the two methods. As was pointed out in the chapter on penetration, the "absolute" values of these changes have no significance, but only the relation between the water content and the property being studied. It is to be noticed, however, that the measurements by the latter method were not begun at 33 per cent, but at 24 per cent, and if a similar range be taken on the curve of figure 11 the total volume changes by the two methods more nearly approach each other. Considering the curves

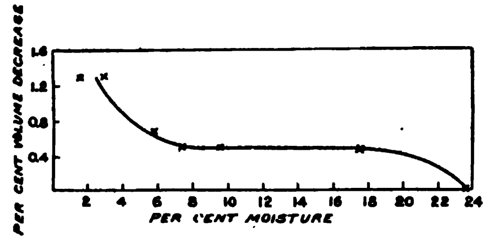

FIG. 12.—Volume-moisture results for Podunk fine sandy loam by the cathetometer method.

within the range of the moisture content covered in the penetration work—namely, 14 per cent to 0 per cent—it will be seen that from 14 to 6 or 7 per cent there is no appreciable change in volume in Podunk fine sandy loam, the loss of water over this range having no influence on the volume of the soil. In the neighborhood of 6 per cent, however, a change is noticeable, a loss of water beyond this point being accompanied by a diminution in the volume of the sample.

Thus, it follows that not only in the penetration but also in the aparent specific gravity a change occurs in the physical properties of the soil at about 6 per cent moisture content, which content is also the optimum. It is evident, therefore, that the optimum water content has an important physical significance and the work on volume contributes much to an understanding of the factors that operate at the optimum water content.

Results for Miami black clay loam.

Very satisfactory volume results were obtained in the measurements on the Miami black clay loam. The nature of the soil made it well suited to the soil column method of measuring volume change; because of its clayey nature and organic matter content it was able to retain the form of the soil column both in a very wet and a very dry condition. Further, the presence of the clay and organic matter caused greater volume changes, which added much to the ease of obtaining results.

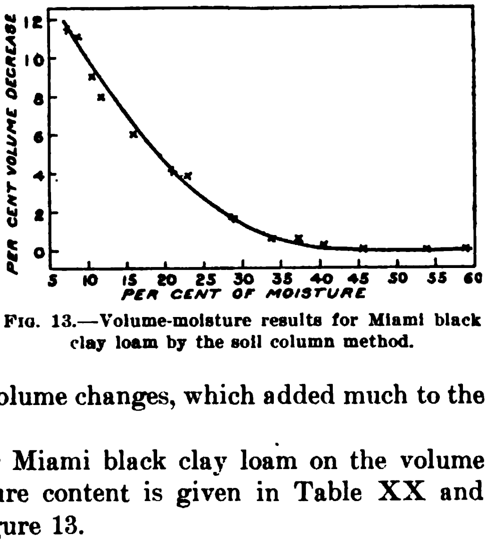

FIG. 13.—Volume-moisture results for Miami black clay loam by the soil column method.

A set of data obtained for Miami black clay loam on the volume changes with varying moisture content is given in Table XX and represented graphically in figure 13.

TABLE XX.—*Volume-moisture relations for Miami black clay loam by the soil column method.*

[Length of soil column, 14 centimeters.]

Moisture.	Linear decrease.	Volume decrease.	Moisture.	Linear decrease.	Volume decrease.
Per cent.	*Centimeter.*	*Per cent.*	*Per cent.*	*Centimeter.*	*Per cent.*
59.0	0.0	0.0	20.9	0.195	4.1
54.0	.002	.0	16.2	.292	6.1
45.7	.002	.0	11.8	.383	8.0
40.4	.011	.2	10.8	.444	9.1
37.4	.022	.5	9.0	.537	11.1
34.0	.028	.6	7.6	.559	11.5
28.8	.078	1.6	6.7	.564	11.6
22.3	.181	3.9			

From this table it is seen that for moisture changes over a wide range near the saturation point there is no change in volume. At about 40 per cent, however, there begins a contraction in volume which continues down to the lowest limit to which the drying was carried. Another curve was obtained by the cathetometer method, the moisture content varying from the saturation point to well below the optimum. At the saturation end of the curve no variation in volume occurred, but at about 35 per cent moisture content a decided contraction began, which continued through the lower moisture contents. These data are given in Table XXI and figure 14.

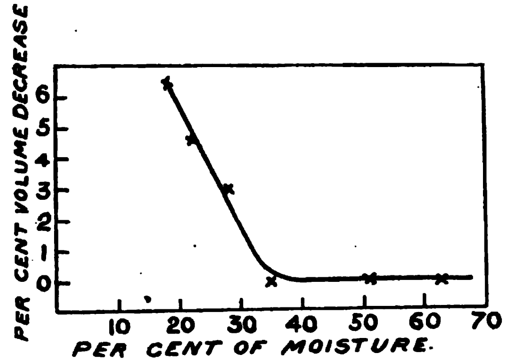

FIG. 14.—Volume-moisture results for Miami black clay loam by the cathetometer mèthod.

TABLE XXI.—*Volume-moisture relations for Miami black clay loam by the cathetometer method.*

Moisture.	Linear decrease.	Volume change.	Moisture.	Linear decrease.	Volume change.
Per cent.	*Centimeter.*	*Per cent.*	*Per cent.*	*Centimeter.*	*Per cent.*
61.2	0.0	0.0	28.2	0.04	3.1
51.8	.0	.0	22.6	.06	4.6
35.0	.0	.0	18.3	.08	6.5

Another set of results on the apparent specific grávity of the different samples is plotted in figure 15, from which it is seen that the results run parallel to the penetration data, as shown in figure 6. Thus, again the volume changes indicate that a change in the physical properties of the soil occurs in the region of the optimum water content.

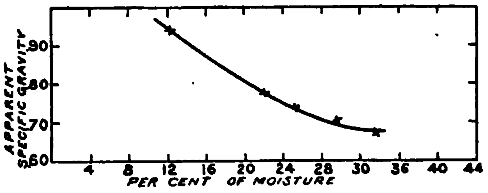

FIG. 15.—Apparent-specific-gravity-moisture results for Miami black clay loam.

Results for Leonardtown loam. The data and curve for a set of measurements on the volume changes in Leonardtown loam are given in Table XXII and figure 16. This curve does not show a marked change in direction at 15 per cent moisture content, and has been added for the sake of completeness to illustrate what may be expected in volume measurements on a soil of this nature. Numerous attempts to take measurements of the volume changes were made with this soil, from which widely varying results were obtained. A few of the forms of curves resulting from different methods are plotted in figure 17, and show that the behavior of this soil is quite irregular.

TABLE XXII.—*Volume-moisture relations for Leonardtown loam by the micrometer method.*

Moisture.	Linear decrease.	Volume decrease.	Moisture.	Linear decrease.	Volume decrease.
Per cent.	*Centimeter.*	*Per cent.*	*Per cent.*	*Centimeter.*	*Per cent.*
33.0	0.0	0.0	22.6	0.194	6.35
32.4	.029	.96	20.6	.209	6.81
30.0	.097	3.19	17.3	.227	7.32
29.2	.119	3.86	15.9	.230	7.46
27.2	.147	4.79	14.7	.235	7.63
26.2	.166	5.38	12.6	.239	7.76
24.2	.176	5.77	11.7	.241	7.90
23.6	.185	6.03			

The variable conduct of this soil may be attributed to its uncertain plasticity, due to the irregular distribution of clay in the soil. As the soil dries out the particles stick together, and when dry the whole becomes cemented into a very hard and compact mass. This cementing of the particles interferes with whatever tendency the changing moisture condition might have to alter the internal arrangement of the soil.[a]

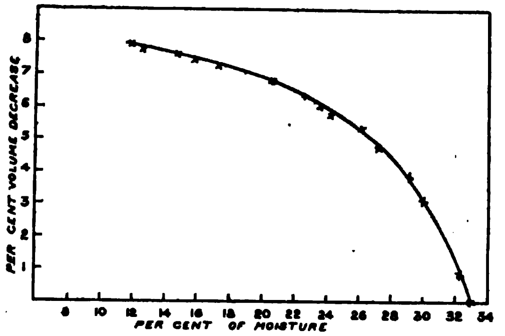

FIG. 16.—Volume-moisture results for Leonardtown loam by the micrometer method.

Upon examination of the curves in figure 2, in which are plotted the penetration results of Puchner, it will be seen that the measurements on clay samples show peculiarities very similar to those encountered in the present work. In the cases in which quartz and humus were in excess the penetration-moisture data all showed maxima in the curves. When kaolin was present in large amounts the penetration values increased steadily as the drying progressed, which action Puchner ascribed to the plastic nature of the material

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[a] The subject of plasticity in clays has been discussed by many writers, and references to a few of the more important treatises are here given: Schlösing, Compt. rend., **74**, 1408 (1872) ; **78**, 1276 (1874) ; Jour. de l'agriculture, **9** iv, 50, 93, 140, 171 (1874) Hilgard, Forsch. auf dem Geb. Agr.-Phys., **2**, 441 (1879) ; van Bemmelen, Landw. Vers.-Stat., **35**, 69 (1888) ; Whitney, Bul. No. 4, Weather Bureau, U. S. Dept. Agr. (1892), p. 27; Ries Clays; Their Occurrence, Properties, and Uses. New York, 1906.

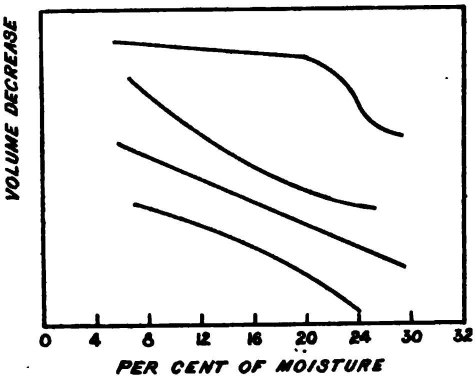

FIG. 17.—Volume-moisture results for Leonardtown loam by the soil column method.

and to the hard, cemented character which the soil assumed on drying out. It is evident from the penetration results for Leonardtown loam that when the sample is worked up into condition at the different moisture contents, the cementing action accompanying drying out is largely prevented.

The apparent specific gravity curve shown in figure 18 was plotted from the data contained in Table XXIII. A similar set of data is given in Table XXIV. In all cases there is a well-defined minimum at 15 per cent moisture content.

TABLE XXIII.—*Relations between penetration, apparent specific gravity, and moisture for Leonardtown loam.*

Moisture, calculated on dry weight of soil.	Weight required for penetration.	Apparent specific gravity.
Per cent.	*Grams.*	
2.8	77	1.07
6.0	59	.980
10.4	48	.865
12.4	49	.841
15.0	43	0.828
15.3	46	.822
17.9	46	.828
20.5	69	.868

TABLE XXIV.—*Relations between penetration, apparent specific gravity, and moisture for Leonardtown loam.*

Moisture, calculated on dry weight of soil.	Weight required for penetration.	Apparent specific gravity.
Per cent.	*Grams.*	
1.8	50	1.01
5.6	40	.812
11.0	34	.695
14.1	34	.690
17.3	40	.723

Results for muck.

This soil proved to be well suited for measurements on volume change by the soil column method, not only because it retained its form on contraction without developing large cracks, but also because it gave fairly large volume changes. The results of the series of values obtained for volume change with varying amounts of water by the soil column method are given in Table XXV, and shown graphically in figure 19.

Table XXV.—*Volume-moisture relations for muck by the soil column method.*

Moisture content.	Linear decrease.	Volume decrease.	Moisture content.	Linear decrease.	Volume decrease.
Per cent.	*Centimeter.*	*Per cent.*	*Per cent.*	*Centimeter.*	*Per cent.*
217.0	0.0	0.0	90.0	0.181	3.8
200.0	.004	.1	83.4	.214	4.46
154.0	.018	.33	67.0	.273	5.81
138.0	.052	1.03	51.1	.372	7.63

From the curve it will be seen that beginning at 217 per cent of moisture, which represents the saturation limit, there is very little decrease in volume over a wide range of moisture content. At 140 per cent of water there is a sharp contraction in the volume which continues down to 45 per cent, the air-dry condition.

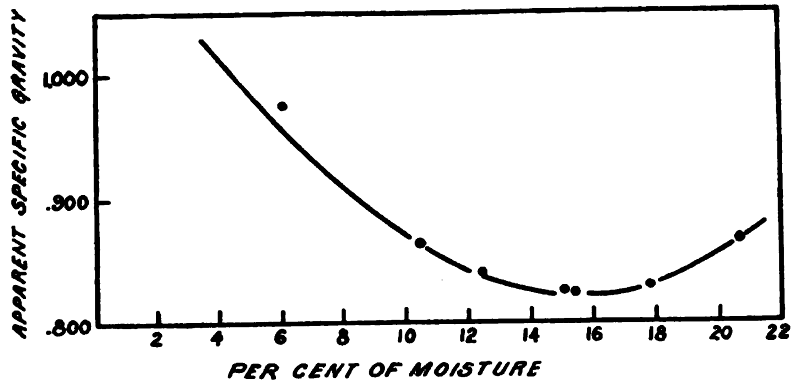

FIG. 18.—Apparent-specific-gravity-moisture results for Leonardtown loam.

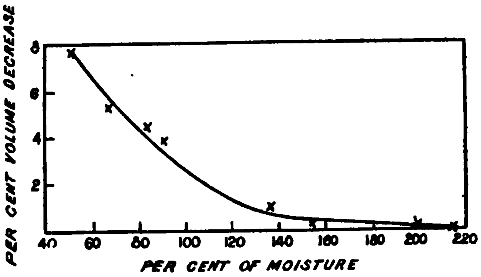

FIG. 19.—Volume-moisture results for Muck by the soil column method.

A series of check results was obtained by the cathetometer method, and is given in Table XXVI and figure 20. The results are quite like those obtained by the column method, indicating that there is a large change between about 140 per cent of moisture and the air-dry condition. It follows that this soil exhibits the same critical changes in physical properties at the optimum water content as were found in the other soils.

TABLE XXVI.—*Volume-moisture relations for muck by the cathetometer method.*

Moisture content.	Linear decrease.	Volume decrease.
Per cent.	*Centimeter.*	*Per cent.*
210	0.0	0.0
185	.0	.0
164	.0	.0
120	.01	.76
84	.08	2.4

In figure 8 corresponding results for penetration and apparent specific gravity are given, the abscissas being common to both curves. It will be seen that the two curves are similar, indicating that it is possible to work this soil into the loosest condition at 120 per cent of moisture, at which point the soil is in the best possible agricultural condition. On the addition of water beyond this point the soil soon becomes too wet to be easily worked, as might be predicted from the rapid rise of the penetration curve.

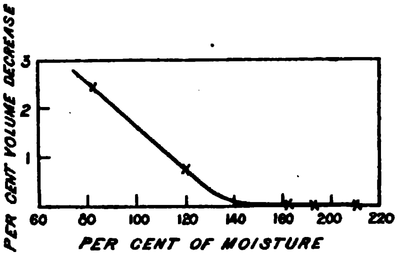

FIG. 20.—Volume-moisture results for Muck by the cathetometer method.

SUCCESSIVE WETTING AND DRYING.

Objects of experiments.

In studying the relation between volume change and moisture content one must consider what constitutes "natural" packing in the soil. It is known that there are large volume changes in soils under field conditions whenever the soil is dried or wetted. These volume changes render it highly improbable that the soil will stay in any condition of packing imposed by an external agency. It is a matter of common observation that when a soil is put into a loose condition by cultivation or other means and subsequently left undisturbed it will settle back in time nearly to its original volume. The relation between the change in volume due to settling and the change in volume due to a variation in moisture content was therefore investigated.

Experimental methods.

The methods of measuring the volume changes were the same as in the volume work described above. When the soil had gone through the process of drying out once it was wetted by capillary rise without in any other way disturbing it. A complete record of the volume measurements was obtained while the soil was drying out; the total change in volume due to wetting was observed without obtaining measurements for the intermediate moisture contents. This cycle could be repeated any number of times, and the variation in soil volume due to continued wetting and drying could be readily followed.

Results for Miami black clay loam.

The results of a set of measurements by the soil-column method for Miami black clay loam in which the original sample was in fairly loose condition are given in Table XXVII. For each cycle the volume decrease has been given in cubic centimeters and in per cent. In the last column is given the total volume decrease referred to the original volume. The separate curves are referred to the same standard for comparison, i. e., the original volume of the sample.

TABLE XXVII.—*Volume changes for the continued wetting and drying of a loose sample of Miami black loam.* (*Soil column method.*)

Cycle.	Moisture content.	Length of column.	Changes during separate dryings.		Total changes from original condition.	
			Linear decrease.	Volume decrease.	Linear decrease.	Volume decrease.
	Per cent.	*Centimeters.*	*Centimeter.*	*Cubic centimeters.*	*Centimeters.*	*Cubic centimeters.*
1	58.2	13.989	0.0	0.0	0.0	0.0
	41.1	13.989	.011	.2	.011	.2
	38.5	13.936	.064	1.3	.064	1.3
	25.2	13.904	.196	4.1	.196	4.1
	19.2	13.545	.455	9.3	.455	9.3
	9.5	13.366	.634	12.9	.634	12.9
	5.7	13.316	.684	14.0	.684	14.0
2	59.0	13.536	.0	.0	.464	9.8
	54.0	13.534	.002	.0	.466	9.8
	45.7	13.534	.002	.0	.466	9.8
	40.4	13.525	.011	.2	.475	10.0
	37.4	13.514	.022	.5	.486	10.3
	34.0	13.508	.028	.6	.492	10.4
	28.8	13.458	.078	1.6	.542	11.4
	22.3	13.455	.181	3.9	.645	13.7
	20.9	13.341	.195	4.1	.659	13.9
	16.2	13.244	.292	6.1	.756	15.9
	11.8	13.153	.383	8.0	.847	17.8
	10.8	13.092	.444	9.1	.908	18.9
	9.0	12.999	.537	11.1	1.001	20.9
	7.6	12.977	.559	11.5	1.023	21.3
	6.7	12.972	.564	11.6	1.028	21.4
3	58.3	13.469	0.0	0.0	0.531	10.5
	55.6	13.428	.041	.9	.572	11.4
	51.4	13.407	.062	1.3	.593	11.8
	37.2	13.373	.096	2.1	.627	12.6
	31.8	13.318	.151	3.2	.684	13.7
	22.1	13.195	.274	5.8	.805	16.3
	19.8	13.131	.338	7.2	.869	17.7
	15.5	13.000	.469	9.7	1.000	20.2
	12.3	12.858	.611	12.5	1.142	23.0
	9.4	12.809	.660	13.5	1.191	24.0
	7.8	12.793	.676	13.8	1.207	24.3
4	59.5	13.282	.0	.0	.718	14.6
	54.5	13.271	− .011	− .08	.729	14.5
	40.0	13.153	+ .029	+ .6	.747	15.2
	32.4	13.114	.068	1.4	.786	16.0
	21.0	13.107	.175	3.7	.893	18.3
	19.3	13.092	.190	4.0	.908	18.6
	14.9	13.027	.256	5.3	.973	19.9
5	56.0	13.218	.0	.0	.782	15.9
	34.8	13.151	.067	1.4	.859	17.3
	2.9	13.071	.147	3.1	.929	19.0

From the data for total volume change it can be seen that there is a decrease in volume on drying out the wet sample. When the dry soil is wet again, there is an expansion, which is not, however, as large as the previous contraction, so that the total effect for the cycle has been to reduce the volume of the sample. The effect of continually wetting and drying a loose sample of soil is better seen from the curves in figure 21, which have been plotted from the data given in the above table.

The volume decrease for the loose soil in drying from a saturated to an air-dry condition was about 14 per cent of the original. This change is represented by curve 1. On again wetting the dry soil, it still showed a volume of 10 per cent less than the original. If on drying out the second time the moisture content had been reduced as low as it was in the case of curve 1, the volume change would have been about 12 per cent. This can be seen by exterpolating curve 2 to a 5 per cent moisture content.

The volume change from the original condition is about 23 per cent; hence at the end of this drying the soil occupies 77 per cent of its original volume. Likewise when this dry sample was wetted again, the expansion was less than the previous contraction, so that at the end of the second cycle the sample was packed still more. The difference, however, between states 3 and 2 is much less than between 2 and 1. The volume occupied by the soil after the third wetting decreased 13.8 per cent on drying out, which indicates that, although the sample is packed more tightly, the contraction in passing from a saturated to an air-dry condition remains about the same. The results for the fourth and fifth dryings are represented by curves 4 and 5, and in general indicate that the changes due to successive wettings and dryings are more nearly identical and that the sample is approaching a condition of " natural " packing.

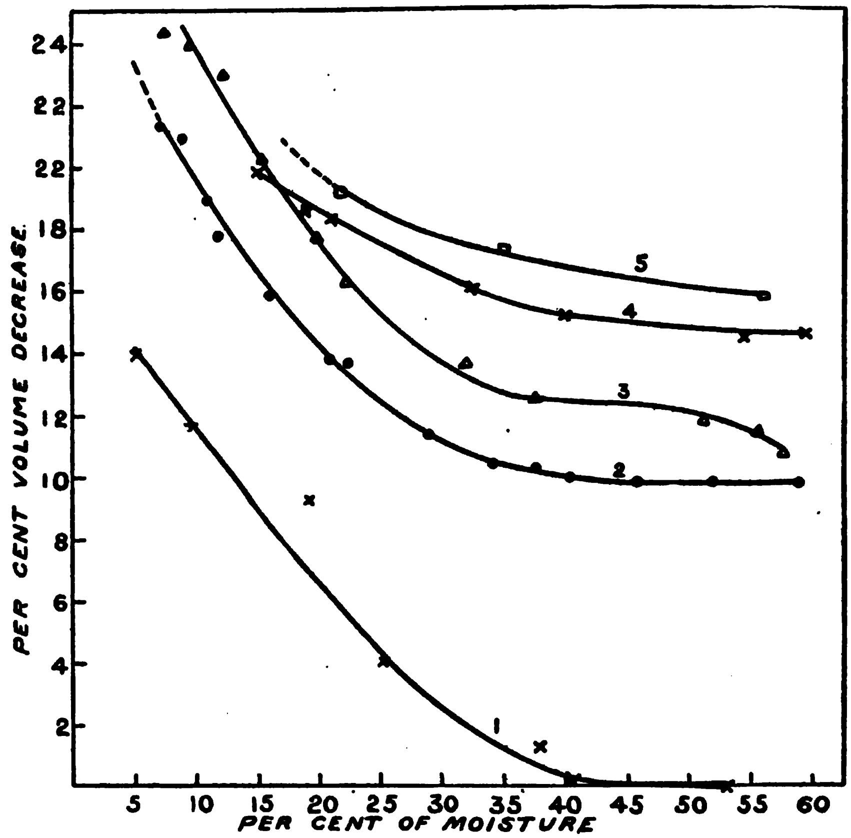

FIG. 21.—Volume changes with successive wetting and drying of loosely packed Miami black clay loam.

By the time curves 4 and 5 were obtained the soil column was in rather poor condition, owing to the fact that the cracks which formed on drying were not repaired in the subsequent wetting, so that the soil column developed points of weakness which interfered with the measurements of the total volume changes. For a continued series of this kind the soil column method would not prove so satisfactory as a method in which the sample is contained in a dish and the height of the soil surface measured. The former method has, however, the distinct advantage of being rapid, since the surface exposed per gram of soil is relatively very much greater than if the sample were contained in a cup. It is probable that the first three curves are more reliable than those obtained when the soil column was weakened by cracks.

These measurements on the continuous contraction of a loose sample of Miami black clay loam lead to the following conclusions:

(1) On drying and wetting a loose sample of soil there is a marked hysteresis effect in the volume changes, resulting in a total contraction in volume for a moisture-change cycle.

(2) On successive wettings and dryings this hysteresis becomes less and less. When it disappears altogether, the expansion on wetting will be equal to the contraction on drying and a condition will have been attained which may be designated a " natural " packing of the soil.

(3) Curves 1, 2, and 3 show that within limits the contraction in drying from a saturated to an air-dry condition is not greatly dependent on the packing.

Results for Muck.

A sample of Muck in a loose condition was found to give similar results for successive wettings and dryings. The contraction on drying out the sample the first time was 29.2 per cent of the original volume. On wetting it increased, however, only 7 per cent; as the result, therefore, of one cycle the volume was 22.2 per cent less than originally. On drying out the second time the volume decrease was 7.6 per cent, which made a total volume decrease of 29.8 per cent.

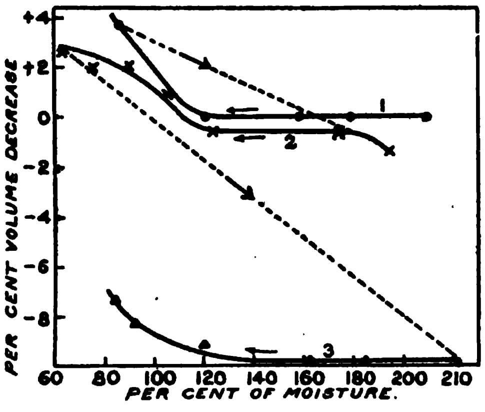

FIG. 22.—Volume changes with successive wetting and drying of closely packed Muck.

That the condition of natural packing in a soil does not represent the closest possible packing is evident from observations made on the successive wetting and drying of a very tightly packed sample of Muck. The soil, in a moderately moist condition, was closely packed into a cup and the change in volume with moisture content was followed by the cathetometer method. The results stated in Table XXVIII are expressed in the same manner as in Table XXVII, except that when the volume of the sample becomes greater than in the original condition the total per cent decrease in volume is assigned a negative value. The original saturated condition is taken as zero on the percentage volume change scale, and increases and decreases in volume are figured down and up respectively from this point. The results are more easily appreciated from the corresponding curves in figure 22. The curves have been numbered in the order of the successive dryings. On drying out the original sample the usual volume contraction is noted. The direction of the change (not the actual path) on wetting is indicated by the arrows on the dotted lines. In this case the expansion on wetting was greater than the previous contraction, and at the end of cycle 2 the sample is in looser condition and occupies a greater volume than at the end of cycle 1. Curve 2 again shows a contraction on drying and a much greater expansion on wetting. Curve 3 also shows the usual contraction on drying.

TABLE XXVIII.—*Volume changes for the continued wetting and drying of a closely packed sample of Muck (cathetometer method).*

Cycle.	Moisture content.	Linear decrease.	Volume decrease.	Difference in volume.	Total volume decrease.
	Per cent.	*Centimeter.*	*Per cent.*	*Per cent.*	*Per cent.*
1....	205.0	0.0	0.0	0.0	0.0
	179.0	.0	.0	.0	.0
	158.0	.0	.0	.0	.0
	120.0	.0	.0	.0	.0
	86.0	.05	3.98	.0	3.98
2....	195.0	.0	.0	−1.32	−1.32
	175.0	.01	.76	.0	− .56
	123.0	.01	.76	.0	− .56
	105.0	.03	2.39	.0	+1.05
	92.5	.04	3.18	.0	+2.08
	75.0	.04	3.18	.0	+2.08
	64.0	.05	3.98	.0	+2.66
3....	210.0	.0	.0	−9.8	−9.80
	185.0	.0	.0	.0	−9.80
	164.0	.0	.0	.0	−9.80
	120.0	.01	.76	.0	−9.04
	92.0	.02	1.58	.0	−8.22
	84.0	.03	2.39	.0	−7.41

In comparing this with the curves representing the continuous changes in a loose sample (fig. 25) the effect of continued wetting and drying is seen to be in an opposite direction. It is possible therefore to pack a soil so tightly that on continuous moisture changes the volume will increase. This hysteresis effect will cease when the expansion due to complete wetting just equals the contraction due to drying out to the air-dry condition, and the soil will then be in the state of natural packing. It has been suggested that within narrow limits the change in volume on contraction was not greatly dependent on the packing. If this were not the case the influence of packing would have to be considered in measurements, such as were made by Wollny and others, on the " total " volume change due to wetting and drying. It has been made clear that unless the condition of natural packing is realized the volume decrease in drying will not be the same as the increase in the subsequent wetting. That the volume changes obtained by previous investigators (see Tables XIV and XV) on wetting a soil were different from those obtained for the same soil on drying was no doubt due to the fact that the samples were not in the condition of natural packing and that the hysteresis effects described above were encountered.

RATE OF EVAPORATION.

RELATION OF RATE OF EVAPORATION TO MOISTURE CONTENT.

Experimental methods.

Since vapor pressure, and hence rate of evaporation, varies with temperature, reliable results could be obtained only when the measurements were made at constant temperature. A large air thermostat was made for this purpose. In order to cut down radiation the walls were built double. The heating was done by electric lamps controlled by the Geer[a] form of electric thermo-regulator. The air was thoroughly stirred by means of a fan, driven from the outside by a motor. By means of this device the temperature could be maintained constant within 0.1° C. In order that the humidity might remain constant during evaporation the samples were put in desiccators over a relatively large surface of 95 per cent sulphuric acid, which maintained a partial vapor pressure of 0.1 millimeter mercury at 25° C., the temperature of the thermostat.

Thus by regulating the temperature and consequently the vapor pressure the conditions for evaporation were controlled satisfactorily.[b]

The method consisted of wetting to its saturation point an amount of soil equivalent to 20 grams of dry material. The weight of the bottle and soil was determined initially and at frequent intervals during the process of drying out in the desiccator. From the loss in weight and the time between successive weighings the rate of evaporation was calculated. From the observed weight of the soil and bottle and the dry weight equivalent of the soil, the moisture content at the time of weighing was calculated. The calculated rate of evaporation was based on the mean water content prevailing over the time in which the loss was occurring, i. e., the mean of the moisture contents calculated from two successive weights.

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[a] Jour. Phys. Chem., 6, 85 (1902).

[b] Under these conditions the rate of evaporation from a dish of water should of course be constant. This was tried experimentally with satisfactory results.

Results for Podunk fine sandy loam.

A series of measurements on the rate of evaporation for Podunk fine sandy loam is given in Table XXIX, and is represented graphically in figure 23.

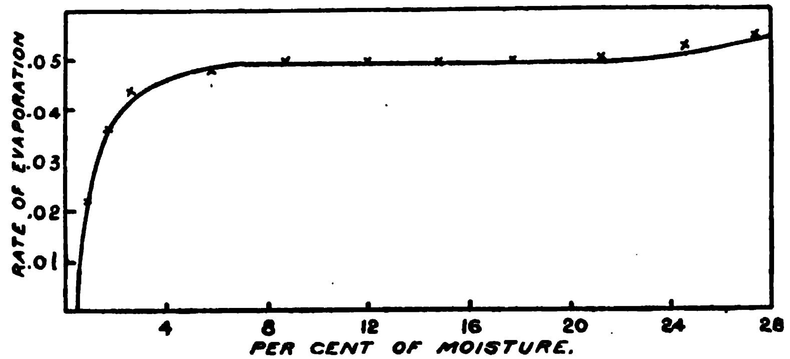

FIG. 23.—Rate-of-evaporation-moisture results for Podunk fine sandy loam.

TABLE XXIX.—*Rate of evaporation from Podunk fine sandy loam over 95 per cent sulphuric acid at 25° C.*

Mean moisture content.	Time interval.	Loss.	Loss per hour.	Mean moisture content.	Time interval.	Loss.	Loss per hour.
Per cent.	*Hours.*	*Gram.*	*Gram.*	*Per cent.*	*Hours.*	*Gram.*	*Gram.*
27.4	19.5	1.0450	0.0536	8.7	14.5	0.7140	0.0492
24.2	4.5	.2362	.0525	5.8	9.9	.4712	.0476
21.3	18.7	.9210	.0493	2.4	4.0	.1782	.0433
17.8	9.3	.4595	.0494	1.7	2.0	.0719	.0359
14.8	15.3	.7495	.0490	.9	11.0	.2445	.0222
12.0	9.9	.4854	.0490	.3	2.0	.0097	.0049

The measurements on the rate of evaporation were begun when the soil held 28 per cent of water. The first evaporation was probably from the surface alone, so at first there is a small decrease in the rate as the water begins to evaporate from the pore spaces. Beginning at 22 per cent of water and extending over a wide range the rate of evaporation remains quite constant. At about 6 or 7 per cent a change takes place, for the rate decreases and continues to fall rapidly as the percentage of moisture decreases. Again, there is an obvious change in the physical properties of the soil at the optimum water content.

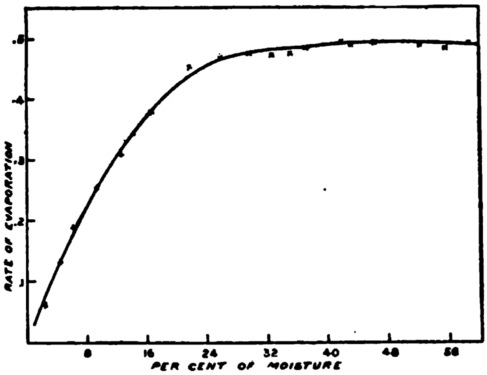

FIG. 24.—Rate-of-evaporation-moisture results for Miami black clay loam.

Results for Miami black clay loam.

On account of the high water content at the optimum in this soil the rate of evaporation method was exceptionally well suited to furnish a comparison of the soil condition at different water contents. The optimum for Podunk fine sandy loam lies so low that the change in the curve for the rate of evaporation might be supposed to be due to the relatively dry condition alone. In the present case the optimum lies about 30 per cent above the air-dry condition, so that changes in the character of the curve for rate of evaporation will be more significant. The data for this curve were obtained in the same way as for Podunk fine sandy loam. The data and the graphical representation are given in Table XXX and figure 24.

The evaporation curve which was started near 60 per cent is horizontal for about 20 per cent decrease in moisture content, showing a uniform rate above the optimum. At about 40 per cent, however, it gradually changes direction, the rate of evaporation falling.

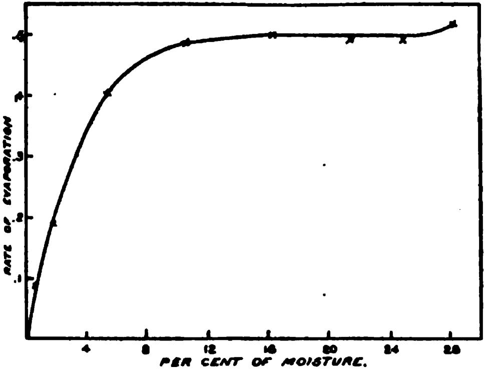

Fig. 25.—Rate-of-evaporation-moisture results for Leonardtown loam.

Table XXX.—*Rate of evaporation from Miami black clay loam over 95 per cent sulphuric acid at 25° C.*

Mean moisture content.	Time interval.	Loss.	Loss per hour.	Mean moisture content.	Time interval.	Loss.	Loss per hour.
Per cent.	*Hours.*	*Gram.*	*Gram.*	*Per cent.*	*Hours.*	*Gram.*	*Gram.*
58.5	16.7	0.8198	0.0491	29.7	7.0	0.3321	0.0474
55.4	9.3	.4474	.0481	26.9	17.0	.7964	.0468
52.4	15.17	.7422	.0489	22.1	24.0	1.0879	.0453
49.4	9.9	.4802	.0485	17.1	24.0	.9109	.0379
46.4	14.5	.7155	.0493	12.9	26.25	.8108	.0309
43.4	9.9	.4808	.0486	9.5	22.25	.5716	.0257
41.0	11.0	.5427	.0492	6.7	24.5	.4694	.0192
37.5	11.0	.5411	.0488	5.1	22.75	.3056	.0134
35.4	6.5	.3099	.0477	3.7	23.75	.2136	.0090
32.6	17.5	.8295	.0474	2.7	24.25	.1470	.0061

For Miami black clay loam the studies in penetration, apparent specific gravity, and rate of evaporation all indicate that the critical moisture content which determines the physical properties of this soil lies between 35 and 40 per cent, which also is the optimum water content of the soil.

Results for Leonardtown loam.

The measurements of rate of evaporation from Leonardtown loam are given in Table XXXI and figure 25.

It has been shown that for this type of soil the volume relations at the optimum water content do not permit of very satisfactory conclusions. However, the penetration and evaporation measurements show critical changes at about 15 per cent of water, the optimum water content of the soil.

TABLE XXXI.—*Rate of evaporation from Leonardtown loam over 95 per cent sulphuric acid at 25° C.*

Mean moisture content.	Time interval.	Loss.	Loss per hour.	Mean moisture content.	Time interval.	Loss.	Loss per hour.
Per cent.	*Hours.*	*Gram.*	*Gram.*	*Per cent.*	*Hours.*	*Gram.*	*Gram.*
28.2	19.0	0.9770	0.0517	10.7	24.5	1.1963	0.0488
24.9	7.25	.3555	.0490	5.5	22.75	.9193	.0404
21.6	19.25	.9538	.0496	2.0	24.25	.4560	.0188
16.4	22.0	1.0962	.0498	.7	24.16	.0904	.0037

Results for muck.

The results for this soil are given in Table XXXII, and have been plotted in figure 26. When the soil in a very wet condition was put over sulphuric acid in a desiccator there was at first a rapid drop in the rate of evaporation corresponding to the decrease as in the previous cases studied. The curves, however, indicate that for a wide change in moisture content it exhibits very little change in the rate of evaporation. At about 120 per cent there is a rapid decrease in the rate of evaporation, indicating that the critical moisture content has been reached. This decrease continues down to 30 per cent, at which point measurements were discontinued.

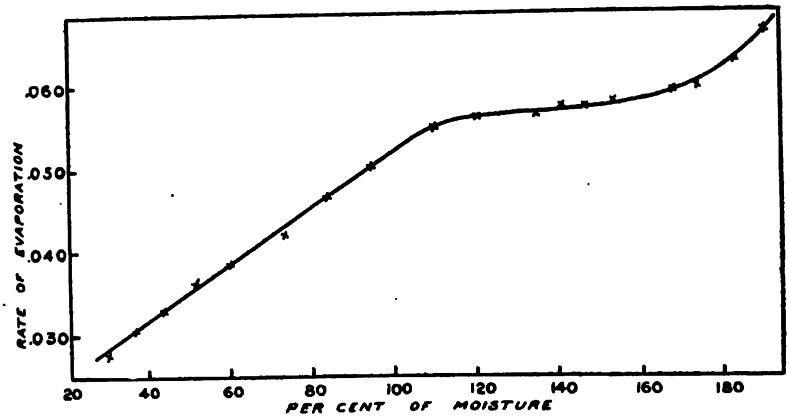

FIG. 26.—Rate-of-evaporation-moisture results for Muck.

TABLE XXXII.—*Rate of evaporation from muck over 95 per cent sulphuric acid at 25° C.*

Mean moisture content.	Time interval.	Loss.	Loss per hour.	Mean moisture content.	Time interval.	Loss.	Loss per hour.
Per cent.	*Hours.*	*Gram.*	*Gram.*	*Per cent.*	*Hours.*	*Grams.*	*Gram.*
190	9.5	0.6362	0.0669	110	24.0	1.3233	0.0551
183	15.2	.9590	.0632	96	24.0	1.2120	.0505
174	9.85	.5905	.0600	84	26.3	1.2332	.0469
168	14.5	.8639	.0596	74	22.1	.9329	.0423
154	10.0	.5813	.0581	60	24.3	.9388	.0387
147	13.0	.7474	.0575	52	23.0	.8352	.0363
141	6.5	.3744	.0576	44	24.0	.7958	.0331
135	17.5	.9898	.0566	37	24.0	.7372	.0307
121	17.0	.9591	.0564	30	24.5	.6851	.0279

MOISTURE DISTRIBUTION.

MOISTURE FILMS.

When to a dry soil a very small amount of water is added by putting the sample in an atmosphere saturated with vapor, there will be a direct condensation on the soil grains, and water will be held partly or entirely in thin films on the surface of the soil particles. Owing to an attraction between the particles and the water at the surface, this absorbed moisture is held with very great force, and the wetting of the soil grains is accompanied by an energy change of considerable magnitude. On wetting a mass of dry soil the formation of this film in the manner stated is accompanied by another effect due to the contact of soil grains. The films merge, so that a number of soil grains may be considered as being covered by one continuous film, and pulled together at the points of contact by the tension of the connecting film. Considering for the moment the formation of the films around the grains, it is evident that as more water is added to the soil and the films get thicker a point will be reached where the surface attraction of the soil particle is no longer strong enough to retain more water, since the surface force decreases rapidly as the distance from the surface increases.[a]

Before this point is reached, however, the thickness of the water films at the point of contact between the grains has been increasing owing to the film tension at the points of high curvature in the angles between the grains.[b] The thin, wedge-shaped angles between the grains will act then as capillary spaces and help to hold water. Since the surface films and capillary films merge, it is impossible to distinguish between them. The forces exerted by these films determine the changes in the internal arrangement of the soil particles and the physical characteristics of the soil.

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[a] Bakker, Zeit. phys. Chem., 56, 95 (1906).

[b] Briggs, Bul. No. 10, Bureau of Soils, U. S. Dept. Agr. (1897).

EFFECT OF MOISTURE DISTRIBUTION ON VOLUME CHANGES.

When a soil is saturated with water the pore spaces are filled. Assuming that these soil capillary tubes are continuous and of uniform diameter, the capillary force holding the water is equal to the pull in an ordinary capillary tube of a similar size. In comparison with the capillary spaces occurring at the contact of the soil grains, these tubes are large, so that the capillary force exerted by them is relatively small. Since the water in the large spaces is not held by great force, it will be the first to evaporate and will have but little effect in changing the arrangement of the grains. As evaporation proceeds a point will be reached where the water begins to evaporate from the fine capillary spaces, which include the angles between the soil grains. At this point the forces of film tension become more noticeable. As the water held between the soil grains diminishes and retreats farther and farther into the angles, the surface film stretches, increasing the film tension and pulling the soil grains inclosed by it still closer together, thus producing a contraction in the volume occupied by the soil. The point where the effective film forces are just sufficient to cause changes in the internal soil arrangement will be designated the "critical moisture content." As evaporation continues still further the surface films around the grains and the capillary wedges held between the grains become thinner. The surface film forces continue to increase; hence the volume should steadily decrease until the soil reaches an air-dry condition.

It is evident from the data given for the volume changes in Podunk fine sandy loam that the above consideration is substantiated by experimental facts, and even more strongly by the volume changes observed with the other soils. Take, for example, Podunk fine sandy loam with about 14 per cent of water. At this point the large pore spaces contain considerable water, and as the soil dries out this water will be the first to disappear. Since the large capillary tubes constitute a relatively large part of the soil space available for water, they will hold a considerable percentage of the water when the soil is saturated. This will be particularly true in this soil, a sand, where the single intergranular spaces are large, owing to the size of the soil particles. The withdrawal of water from the larger pore spaces will therefore cause a large decrease in the moisture content of the soil. When the moisture content of the soil is about 6 per cent, the critical water content is reached and a change in volume begins.

It will be remembered that for volume changes in Podunk fine sandy loam a large volume contraction occurred between 33 and 18 per cent of water, between which limits the soil is too wet to ascribe the variation to the tension of the surface films. As the measurements were made on fairly loose samples of soil, it is quite possible that this volume change was caused simply by a gradual settling of the wet soil particles. When wet beyond a certain point a sand becomes incoherent. The soil aggregates seem to break down and the grains slip easily over one another, the excess of water acting as a lubricant and reducing the friction between the grains. It is possible that the volume changes occurring near the saturation point may also, in part, be due to a tendency of the free water to buoy up the soil grains and in this way decrease the packing of the grains by lowering the effective specific gravity of the individual grains. As the wet soil dries out, this tendency decreases and vanishes at a content of water a little below the saturation point.

The larger volume changes due to addition of water in clay soils is sometimes attributed to the presence of large amounts of colloidal material, which is supposed to imbibe the water and swell like starch grains. This view can easily be brought into agreement with the above theory of volume change. The question of absorption in a cell has been quite fully considered by Kauffler [a] and it has been shown by Patten[b] that absorption with imbibition can be considered as a special case under absorption. For our purpose, therefore, it makes no difference whether the volume change is due to action on the exterior surface of the particles or to imbibition accompanied by an increase in size of the particles. In the case of a peat soil, for example, it seems entirely reasonable that on account of the nature of the material a large change in volume is due to imbibition and swelling of the cells. There is no reason why a similar view should not be held for clay, although here it is quite possible to explain the phenomena without recourse to this idea. The volume changes in clay are very much greater than in sand. On account of the large difference in soil surface in a similar volume of the two classes, we would also expect the capillary and film effects in clay to be very much greater. The proportion of the relative areas exposed by equal volumes of very fine sand and of clay may be as great as 1 to 300, a difference which is quite sufficient to explain the large differences in volume changes in the two soils, on the basis of surface absorption and surface tension.

EFFECT OF MOISTURE DISTRIBUTION ON PENETRATION.

Having shown that volume changes in soils can be explained on the basis of the forces exerted by the capillary and surface films around the grains, and that the critical water content for volume-change and that for penetration are identical, it remains to be seen how the above considerations regarding the distribution of water in the soil explain the phenomena observed in the penetration experiments.

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[a] Zeit. phys. Chem., **48**, 686 (1903).

[b] Trans. Am. Electrochem. Soc., 11 (1907).

Consider first the case of penetration under conditions of loose structure. The variations in the penetrability of the soil were attributed to the ability of the soil grains to arrange themselves into aggregates. In a dry soil the cohesion between the grains is that of one dry, solid body for another, and is readily seen to be small. The particles are thus quite free to move each other and tend to settle down into a compact condition. When a small amount of water is added to the soil, it gathers over the surface as films and settles into the angles between the soil grains. The cohesion of the soil particles increases and the action of surface tension promotes the formation of floccules and increases the possibility of building up the soil into a loose structure. As more water is added the thickness of the films and the amount of water held in the angles between the grains increase, the cohesion increases, and the soil responds better to cultivation. This effect reaches a maximum when the amount of water that can be held in this way reaches a maximum, and will be indicated by the fact that a minimum amount of force will be necessary to penetrate the soil sample. Since the loosely arranged soil grains in this condition occupy the smallest possible percentage of the total volume of the soil, the remainder of volume being taken up by air, the resistance to the introduction of a penetrating tool is a minimum at this point.

The further addition of water beyond the critical moisture content begins to fill up the larger pore spaces and to flood the soil. The soil aggregates begin to break down, thereby increasing the force necessary for penetration. This is shown by a gradual rise in the penetration curve beyond the minimum. Parallel results are, of course, indicated on the apparent specific gravity curves. The variations in penetration with moisture content is therefore related to differences in the distribution of water in the soil.

This same theory of soil moisture distribution accounts for the penetration results obtained by the Puchner method, where the critical water content for penetration was indicated by a maximum. As dry soil was packed into the containing vessel, the sample can be considered to represent a "single grain structure." The wetting of this dry sample must have been accompanied by an increase in volume, which caused an upward movement of the soil surface and a horizontal thrust upon the sides of the vessel. This acted as a packing force to the already close arrangement. The wetting of the soil also caused an increase in cohesion, as has been pointed out above. If the penetration measurements, therefore, had been made first on the dry sample and then on the sample corresponding to the maximum cohesion, there should be noted an increase in the penetration value. When a soil is saturated with water, the flotation effect tends to suspend the particles and decrease the packing. The excess of water, which renders the soil incoherent, acts as a lubricant, and increases the ease with which the soil grains slide over each other. At saturation this effect is greatest, so that the resistance to penetration is least. As the percentage of water decreases, this effect decreases, and the penetration values rise as shown by the curves. When the water disappears from the larger pore spaces, the critical moisture content and the point of maximum cohesion is reached, at which point the packing effect due to wetting the soil in a confined space is still in force so that the penetration value is high. As the amount of water further decreases there is a decrease in volume due to drying as already shown and a corresponding diminution of this horizontal thrust on the walls of the dish which causes a decrease in the penetration value. Therefore for a soil sample treated in this way the maximum force required for penetration is necessary at the critical moisture content. In the case of Podunk fine sandy loam the occurrence of the critical point in the penetration-moisture relations in both methods of measurement at about 6 per cent of moisture is not a mere coincidence, but is due to the same fundamental forces exerted by a certain quantity of soil moisture in its distribution upon the soil particles.

The change in the physical properties of a soil may be referred to one particular percentage of water only in case the distribution of the water in the soil is entirely uniform, which condition of course does not occur ordinarily. The distribution of water is affected in some measure by the size of the grains, irregularities in packing, gravity, and other variables which can not be controlled. The condition which has been described as influencing the internal arrangement of the soil grains can not then be correctly ascribed to a single point in the moisture variation, but must be considered as operating over a more or less narrow range of moisture content and subject to slight variation from sample to sample of one soil. Also, the measurement of this range may give slightly different results, depending on the method used. From a theoretical point of view the variation in range due to differences in the conditions prevailing does not detract from the value of the results or of the conclusions reached, since the cause of this variation is clear.

EFFECT OF MOISTURE DISTRIBUTION ON RATE OF EVAPORATION.

A further confirmation of the view that the content of soil moisture determines the physical properties of the soil is furnished by the investigation on the rate of evaporation of soil water from soils containing different percentages of water. It has been pointed out that a great difference must exist between the forces with which the water is held in the larger pore spaces and in the capillary angles between the grains. From this the conclusion follows that there must be a corresponding difference in the rate of evaporation.

As the water evaporates out of the larger pore spaces, the rate of evaporation will be determined by diffusion and by the forces of capillarity. Since a considerable quantity of the total soil water is held in the larger pore spaces and since the capillary pull in these spaces is not great in comparison with the forces exerted in the fine angles between the grains, the influence of capillarity upon evaporation from the large spaces will be relatively small. In relation to the rate of evaporation much of the intergranular space can be considered to be of the same order of magnitude, for which reason the rate of evaporation over a considerable range will not decrease very rapidly while the soil is drying out. As the evaporation continues the water held in these pores will disappear, and the soil water will be distributed almost entirely in the fine capillary angles between the soil grains and on the grains as films, where the greater capillarity holds it more strongly. Below this critical moisture content there will be a gradual falling off in the rate of evaporation, due to the increasing attractions between the water and the soil, causing a lowering of the vapor pressure of the absorbed films. Where the thickness of the film is such that the surface attraction just begins to cause a lowering in the vapor pressure of the film, the equilibrium point between the soil moisture and a saturated atmosphere of water vapor is reached, and in such an atmosphere no further evaporation of water from the soil grains takes place. In the open air, however, we are not dealing usually with a saturated atmosphere, and so evaporation will continue from the soil, but under constantly decreasing vapor pressure of the absorbed water, which in turn will cause a corresponding decrease in the rate of evaporation. When the vapor pressure of the soil films corresponds to the partial pressure of the moisture in the atmosphere, evaporation will cease, equilibrium having been reached between the vapor in the air and the film water.

Below the critical moisture content there will be a decrease in the rate of evaporation due, first, to slower diffusion of the water vapor from the finer capillary spaces, and, second, to an increase in the film tension accompanied by a decrease in the vapor pressure of the film water. These two effects merge gradually one into another, so that a smooth curve showing the decrease in evaporation is the result, the rapid decrease in evaporation beginning when the water in the larger pore spaces has nearly disappeared.

CRITICAL MOISTURE CONTENT AND MOISTURE EQUIVALENT.

That there is a connection between the critical moisture content and the distribution of soil moisture follows, also, from recent work done in this Bureau.[a] By means of a centrifugal machine a wet soil sample was subjected to a force about 3,000 times that of gravity, which tended to throw the water from the soil. Even when subjected to such a force it was impossible to reduce the soil sample to an approximately dry condition; in fact, the resulting soil samples contained enough moisture to correspond to good field condition. It is evident from this that part of the water is held in the soil by very strong forces. The only moisture removed from the soil was that held in the larger pore spaces. When the moisture content of the soil is reduced to the point where the water is held in the form of films and as capillary water between the soil grains, it is retained more tenaciously. It was also pointed out that the amount of water removed from the soil is not directly proportional to the centrifugal force used; that is, the soil can be reduced from very wet to a medium condition by a relatively small force. If at this point the speed be doubled, which means that the centrifugal force will be quadrupled, the further reduction of moisture content is comparatively small. This is in agreement with the conclusions reached from the present studies on the rate of evaporation from soils. Instead of measuring the retentiveness of the soil in terms of centrifugal force, here the effect of such a retentiveness on the rate of evaporation has been measured. When the soil moisture is held in the larger pore spaces, the rate of evaporation is fairly constant and not very much less than would be obtained under similar conditions from a free water surface. In other words, the retentiveness of the soil is not very great as indicated by the rate at which that part of the soil moisture evaporates. However, when the critical moisture content is reached, the rate of evaporation immediately begins to decrease, indicating that the soil water is held by greater forces in the finer capillary spaces. As the water surfaces retreat farther into the angles between the grains and the films on the grains become thinner, the forces holding the soil moisture in place increase; this in turn produces a decrease in the rate of evaporation. The results obtained by the centrifugal method agree with the rate of evaporation results, indicating the point at which the larger soil forces come into play. To compare these two methods of studying the distribution of soil moisture one may use the measurements of Briggs and McLane on Norfolk fine sandy loam and the measurements above recorded on Podunk fine sandy loam. The Norfolk fine sandy loam very closely resembles the Podunk fine sandy loam in its physical characteristics. This similarity is shown in part by the comparison of the mechanical analyses of the two soils given in Table XXXII.

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[a] Briggs and McLane, Bul. No. 45, Bureau of Soils, U. S. Dept. Agr. (1907).

TABLE XXXIII.—*Mechanical analyses of Podunk fine sandy loam and of Norfolk fine sandy loam.*

Soil.	Fine gravel, 1 to 2 millimeters.	Coarse sand, 1 to 0.5 millimeter.	Medium sand, 0.5 to 0.25 millimeter.	Fine sand, 0.25 to 0.1 millimeter.	Very fine sand, 0.1 to 0.05 millimeter.	Silt, 0.05 to 0.005 millimeter.	Clay, 0.005 to 0.0 millimeter.
Norfolk fine sandy loam	0	0.5	4.8	54.6	13.4	18.1	8.5
Podunk fine sandy loam	0	0	1.0	47.6	30.4	18.8	2.2

From this comparison it is seen that both soils contain a larger percentage of fine sand than of any other separate and that the quantities in the two soils are comparable. The Podunk soil contains somewhat more very fine sand than the Norfolk soil. The amount of silt is the same in both cases, but the amount of clay in the Podunk fine sandy loam is less than in the Norfolk fine sandy loam. By means of the centrifugal method the "moisture equivalent" was found to be 6.5 per cent of moisture. The critical condition of soil moisture for Podunk fine sandy loam, determined by the rate of evaporation method, was found to be 6 per cent, which is in agreement with the critical moisture value for this same soil as determined from the penetration and volume-change studies. The value obtained from the similar Norfolk fine sandy loam by the centrifugal method is just a little higher, which may easily be attributed to the higher clay content of that soil, since we know that the clay in a soil exerts a large influence on its water-holding power. As no determinations are available for the "moisture equivalent" of Muck or of the Miami black clay loam, there is no basis for comparison of these results. It is possible, however, to compare the sample of Leonardtown loam used in our investigations with a Hagerstown silt loam and a Clarksville silt loam, studied in the centrifugal work of Briggs and McLane.

A comparison of the mechanical composition of these three soils is given in Table XXXIV.

TABLE XXXIV.—*Mechanical analyses of Leonardtown loam, of Clarksville silt loam, and of Hagerstown silt loam.*

Soil.	Organic matter.	Gravel, 2 to 1 millimeters.	Coarse sand, 1 to 0.5 millimeter.	Medium sand, 0.5 to 0.25 millimeter.	Fine sand, 0.25 to 0.1 millimeter.	Very fine sand, 0.1 to 0.05 millimeter.	Silt, 0.05 to 0.005 millimeter.	Clay, 0.005 to 0.0 millimeter.
Leonardtown loam	....	0.1	1.2	0.9	3.1	6.4	70.9	16.7
Clarksville silt loam	1.2	1.2	1.4	.9	2.0	5.6	73.2	14.8
Hagerstown silt loam	1.0	.3	.6	1.5	9.1	10.5	60.3	17.4

Clarksville silt loam more closely resembles the Leonardtown loam than does the Hagerstown silt loam. In all of these soils silt is in excess, varying from 60.3 to 73.2 per cent for the three soils. As regards this point, the Leonardtown and the Clarksville soils are closely comparable. The clay contents are about the same, being slightly higher in the Hagerstown silt loam. The "critical moisture centent" was found to be about 15 per cent for the Leonardtown loam. The "moisture equivalent," as determined by the centrifugal method, for the Clarksville soil was 15.1 and for the Hagerstown sample 16.5. From the close similarity in the mechanical composition and in the moisture values given, it would appear that the *critical moisture content* corresponds to the *moisture equivalent* as determined by the centrifugal method, as well as to the optimum water content, as determined by plant growth and cultural practices.

OPTIMUM WATER CONTENT AS REGARDS PLANT GROWTH.

The usual definition of optimum water content is that amount of water in the soil which is best suited to plant growth. But no emphasis has been placed on this during the course of the previous discussion, where it has been spoken of more often as the amount of water determining the best physical condition of the soil. It can be shown that the amount of water determining the best physical condition of the soil is generally the amount of water most favorable to plant growth. In this connection some evidence is given by Heinrich,[a] who determined the amount of water present in the soil when wilting of plants begins. In the six soils used determinations were made of the point of saturation, of the moisture content at which plants wilt, and also of the hygroscopic water content. This last was done by spreading the soil on a watch glass and exposing it for a week to an atmosphere saturated with water vapor. The results of this investigation are given in Table XXXV.

TABLE XXXV.—*Relation between hygroscopic moisture content and moisture content at which plants begin to wilt, according to Heinrich.*

Soil.	Water content at saturation.	Hygroscopic water content.	Moisture content at which plants begin to wilt.
	Per cent.	*Per cent.*	*Per cent.*
Coarse sand	26.5	0.42	1.5
Medium fertile garden soil	43.9	1.68	4.6
Infertile sandy muck	41.4	.97	6.2
Sandy loam	43.3	2.40	7.8
Very fertile calcareous soil	38.3	3.65	9.8
Peat soil	274.0	20.6	49.7

From this table it is evident that hygroscopic water is not sufficient to supply the needs of a plant, but it indicates also that the plant can exist on a relatively small amount of water. In comparison with the moisture content at which wilting occurs, the amount present in the soil at the critical moisture content is large indeed, and seems to be entirely sufficient for good plant growth. A possible objection is that the optimum water content is not the same for all plants, but from the above consideration it is evident that at the critical water content enough water is present for a good, if not an optimum, plant growth. In further experiments on two soils in continuation of the experiments just described the wilting points were determined for a large number of field crops. These results are given in Table XXXVI.

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[a] Zweiter Ber. Landw. Vers.-Stat. Rostock, 1894, 19.

TABLE XXXVI.—*Moisture content at which wilting begins for two soils, according to Heinrich.*

Plant.	Moisture content at which plants begin to wilt.	
	On calcareous soil.	On peaty soil.
	Per cent.	*Per cent.*
Oats	8.4	3.23
Barley	9.98	33.3
Rye	9.55	32.8
Wheat		43.6
Corn	7.91	
French rye grass (*Arrhenatherum elatius*)		33.2
English rye grass		33.1
Meadow foxtail		34.2
Soft brome grass		32.8
Red clover	10.28	34.3
Sweet clover	8.77	
Lambs clover	9.24	
Crimson clover		34.1
Alfalfa	8.9	
Vetch		35.3
Esparcet	9.92	
Fire bean	11.04	
Horse bean	11.30	
Potatoes	5.07	41.4

Considering the possible variations due to the difficulty of making close representative moisture determinations in soils and the experimental difficulty of correctly judging the time of wilting, there is a striking agreement in the above results for various plants. The average for the calcareous soil is about 9 per cent of water, from which figure there is no striking variation in any of the cases considered, and the average for the peat is about 34 per cent of water.

The general belief that different plants require different optimum water contents in the soil seems to be a result of observations on the total amount of water that the plant actually requires rather than on the percentage in the soil best suited to its needs. The transpiration in one plant may be greater than in another, and the corresponding demand for water would be greater. Investigators in this field have usually supplied the extra amount of water demanded for this larger transpiration by increasing the total water content of the soil rather than by supplying more water as it is needed. That is, instead of gradually supplying a larger amount of water and maintaining the moisture content of the soil near a constant percentage, the same result is obtained by increasing the percentage of water in the soil at one time. The idea that there are different optimum water contents for the same soil for different plants may, therefore, be an outgrowth of the prevailing methods rather than of critical experimentation. Moreover, the idea that there are different optimum water contents corresponding to different plants has apparently been confused with the fact that some plants have more endurance under adverse moisture conditions than have others. These same plants may be able to grow in a large excess of water without great apparent injury, but actually require less for more favorable growth. The fact that one plant can tolerate larger amounts of water than another without serious injury does not alone justify the conclusion that the optimum water content differs for each.

From this work, showing the moisture content approximately constant with any one soil at which wilting of different plants begins and from the other considerations presented, it seems probable that the optimum water content is that which makes for the greatest aeration, loosest structure, and, in general, most favorable physical condition of the soil.

APPARATUS AND METHODS.

SCREENING APPARATUS.

In beginning work on penetration of soils in the loose condition, it was recognized that there existed a serious difficulty in obtaining a uniform packing and so arranging the conditions that the same grade of packing could be obtained on successive trials, thus insuring duplicate results. A preliminary investigation was made on the effect of packing on penetration. The firmness of the packing was determined from the weight of the soil, since the measurements were all made under one moisture condition and the soil was leveled in such a way that the same volume was always obtained. The change in packing was effected by jarring the dishes and by varying the method in which the soil was put into the containing vessel. The results of such a series of measurements on Leonardtown loam containing 9.1 per cent of water are given in Table XXXVII.

TABLE XXXVII.—*Influence of packing on penetration.*

Weight required for penetration.	Weight of soil.
Grams.	*Grams.*
70	1,785
75	1,808
85	1,830
113	1,902
175	1,965

When these results are plotted, using the weights of the soils as abscissas and the weights for penetration as ordinates, a smooth curve is obtained, showing that the penetration is not in direct proportion to the weight, but increases more rapidly. But for a small variation in packing, such as would be met under ordinary experimental conditions, the penetration is, for all practical purposes, a linear function of the packing. This is confirmed by the following measurements made on Leonardtown loam, which held about 15 per cent of water, its optimum water content.

TABLE XXXVIII.—*Influence of packing on penetration.*

Weight required for penetration.	Weight of soil.
Grams.	*Grams.*
64	1,702
71	1,719
87	1,739

These results when plotted lie on a straight line and indicate that soil variations or manipulations cause considerable differences in packing which, in turn, interfere with all measurements on penetration. The importance of having a satisfactory method of packing is therefore evident. Uniform packing is realized only when the process is entirely mechanical.

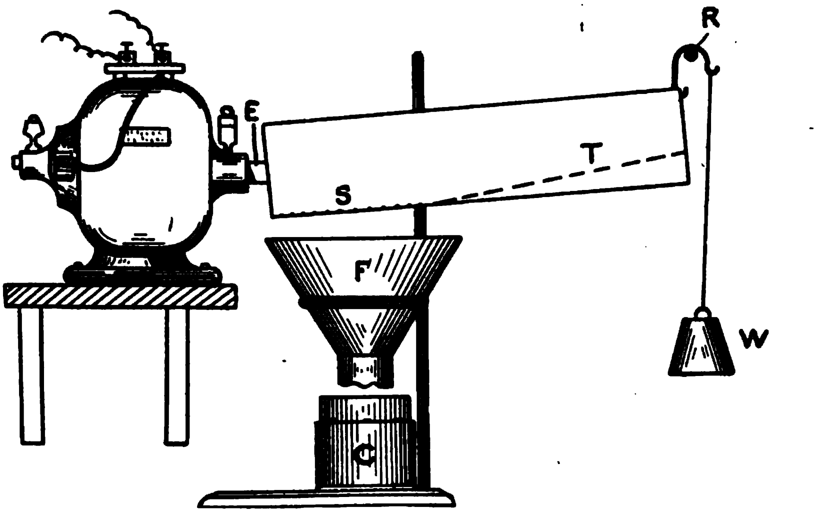

FIG. 27.—Apparatus for screening soils.

The apparatus finally used is shown in figure 27. To the shaft of an electric motor is fastened an eccentric *E*, made from a rod 2 centimeters in diameter, in which the shaft hole is drilled 0.5 centimeter off center. This eccentric fits into a hole in one end of the screen box *ST*. The motion of the revolving eccentric gives the screen a rapid shaking in both vertical and horizontal planes, which is very effective in forcing the damp soils through the mesh. The screen *S*, which is of 3 meshes to the centimeter, is in only one end of the box. A false bottom *T*, made of tin, serves to feed the material toward the mesh during shaking. The upper end of the box is supported by means of two hooks, resting on a horizontal rod *R*, shown in cross section in the figure. The hooks are made of heavy insulated electric-light wire, the covering of which serves to reduce the noise caused by rattling. Further, to prevent rattling at that end of the screen, a kilogram weight *W* is hung between the hooks. With this method of support the upper end of the screen is free to move, yet the motion is so reduced that during shaking the box stays well in position. The soil, after passing through the screen, falls into a funnel *F* and from there into the cup *C*, which holds the sample during the remainder of the experiment.

The cup proper is 12.5 centimeters in diameter and 9 centimeters high, having a capacity of 1,100 cubic centimeters. A rim is added, which makes it possible to fill the cup above its own level. The rim is then removed and the soil leveled off to the edge of the cup. This gives a more uniform packing in the upper layer of the soil.

The shaker makes it possible to repeat the packing of the same sample and also gives a basis of comparison in the measurements made on different samples, since the soil in each case is treated in the same way, falls through the same distance, and therefore is subjected to the same packing forces. Reproduction of these conditions is essential in a series of measurements made upon samples containing different quantities of water, where it is desirable that the only variable entering should be the water content.

PACKING APPARATUS.

The soil sample packed by the method just described is put into a uniform condition for experiment. Starting with the soil sample thus prepared it is possible to vary the packing in a definite and known way and thus study the effect of packing on the physical condition of the soil. The packing is done by the arrangement shown in figure 28, where a front and side elevation of the apparatus is shown. A vertical shaft of brass *AB* works easily through a wooden guide block *G*. On the bottom of the shaft is a circular plate *B* of hard rubber, just a little smaller than the inside of the cup *C*, into which it fits when packing the soil. On the upper end of the shaft is another plate *A*, which serves as a scale pan for the weights *W*, which are of lead and so made that they can be placed in the middle of *A* and concentric with one another, thus avoiding any serious side thrust where the rod passes through the guide. The shaft and plates are connected over pulleys with a weight *L*, by which they are balanced. In order to have the cup *C* still full after packing, a rim *R*, 4 centimeters high, is put on the cup. The screened soil is leveled to the upper edge of *R* and packed under any desired weight at a steady pressure for four minutes, after which the rim is removed and the soil surface reduced to the level of the cup proper. The sample is then ready for the penetration tests.

The behavior of the soil when packed in this way is indicated in figure 29, where a series of measurements for Podunk fine sandy loam containing 2.3 per cent water is shown. In addition to the packing caused by the soil falling from the screening machine, the soil was further compressed under pressure of 10, 30, and 50 grams per square centimeter. These pressures correspond to weights of 1, 3, and 5 kilos, the area of the compressing plate being about 100 square centimeters. The curve indicates that the increased packing pressure applied in this manner gives a fairly uniform increase in the force required for penetration.

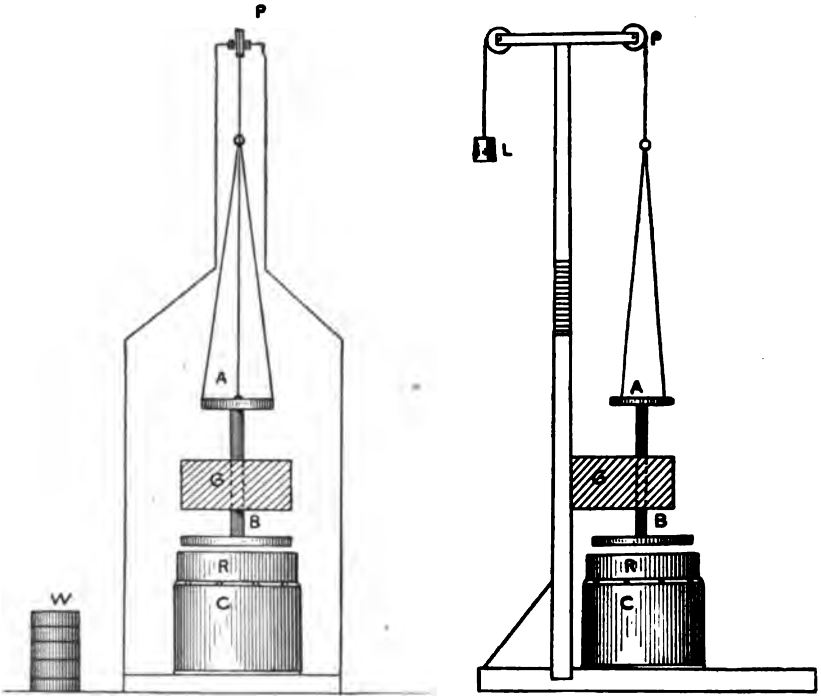

FIG. 28.—Apparatus for packing soils.

PENETRATION APPARATUS.

The force required for penetration was measured on the apparatus shown in figure 30. The penetrating tool *A* is made from a steel rod 1 centimeter in diameter. This is turned into the form of a cone 10.5 centimeters long and 1 centimeter in diameter in the thickest part. The large end of this cone terminates in a tongue which is so fastened to the scale beam *AB* that it is free to swing in the vertical plane of the beam. The beam itself, made of oak, is 140 centimeters long from the end *A* to *D*, the point of rotation. A counterweight *W* balances the beam and its attachments. Midway between *A* and *D* a pail *P* is hung, into which sand is run from a funnel *F* through a rubber tube closed by a pinchcock. This gives a method of constantly adding weight without jarring and of increasing the pressure to just the value necessary to force the tool into the soil to the required depth. The scale beam is guided beteween the upright parallel rods *G*, spaced to allow a free movement of the beam between them. M_1 and M_2 are clamps that check the up-and-down movement of the beam. The depth to which the point penetrates is determined by the position of M_2. The measurement is always begun at the same height—the level of the cup, which was also the soil level—and weight is added until the beam reaches M_2, by which time the tool has penetrated 6 centimeters into the soil. The approach of the beam to M_2 is observed by means of a small mirror *R* fastened at an angle to M_2.

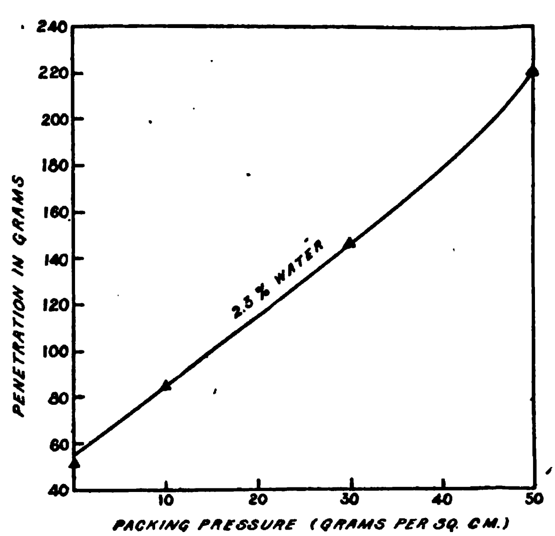

FIG. 29.—Penetration-packing results.

In making a penetration measurement the procedure is to make up a large soil sample to the desired water content, which is then determined accurately by drying a sample at 110° C. and calculating as per cent on the dry weight of soil. This method makes the different water contents of the same soil comparable one with another. The total sample is well mixed by screening and placed in a tightly covered pail. This holds enough soil to permit of repeating the measurements same place when another measurement is to be made. As the drying occurs only at one end of the soil column an error is introduced, since the top of the soil was drier than the bottom. However, in a soil column of this length, if the drying proceeds slowly, this difference in moisture content of the top and the bottom is not very marked. More serious difficulty might be caused by the adhesion between the soil and surface of the glass, which would seriously cut down the influence of changing moisture content on the volume. It is evident from this preliminary attempt that a method suitable for accurate volume work should embody the following points: (1) In order to shorten the time required for carrying through one experiment it is essential that the drying out of the wet sample be rapid; this can be accomplished by exposing as great an area per unit volume of soil as possible. (2) The thickness of the soil from the drying surface down should be small in order that no large difference in moisture content may occur between the top and the bottom of the sample. (3) Since the change in volume is measured by the linear contraction it is essential to have the length in this one direction as great as possible. (4) The soil should be supported in such a way that after drying out it can be wetted again by capillarity without otherwise disturbing the sample, thus making it possible to use the same soil sample through several cycles of moisture change. (5) The soil sample should also be supported in such a way that it is independent of the measuring apparatus and movable at will, so that the same micrometer may be used to measure several samples drying out at the same time. These considerations led to the development of the " soil column method."

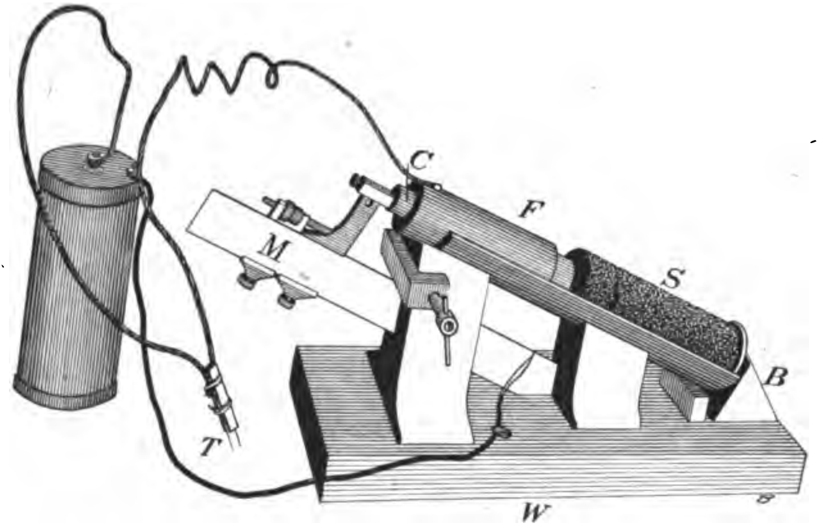

FIG. 32.—Apparatus for soil column method of measuring changes in soil volumes.

Soil column method.

The apparatus used in this method is shown in figure 32. The soil column *S* is molded in an apparatus similar to that shown in figure 31, where the soil is either put in dry and wetted by capillarity or packed into the tube in moderately moist condition, in which state it holds together well when pushed out of the tube onto the brass support shown in the figure. This support is made by cutting longitudinally a brass tube of a diameter a little larger than that of the soil column. Into one end of the support a circular brass disk is screwed so that it is perpendicular to the axis of the tube. Against this disk the lower end of the soil column rests. The disk is perforated so that a column can be wet by capillarity by simply dipping the lower end of its support into water, thus rewetting the sample without in any other way disturbing it. In this arrangement a large surface of soil is exposed to evaporation, and drying proceeds with considerable rapidity. A wet column of this kind reaches the air-dry condition in two to five days, depending on the nature of the soil. This method also insures a comparatively uniform moisture content from the top to the bottom of the sample. Resting against the upper end of the soil column is a brass follower *F* made from heavy brass tubing by inserting into the two ends pieces turned from solid brass. The part projecting from the lower end is made somewhat smaller than the tube so that it will not come in contact with the surface of the soil support, because upon contraction enough soil is left to roughen considerably this surface. The upper end contains a contact piece *C* turned from a brass rod. This is so arranged that by means of a screw, shown in the figure, it may be adjusted to lengthen or shorten the follower. By means of this adjustment the total length of the soil column and the follower can be made nearly the same in different samples, thus adapting the limits of the micrometer screw to their measurement. The Vernier scale and micrometer screw are shown at *M*. As the soil contracts during the wetting, the inclination of the support and the weight of the follower are sufficient to keep it pressed down against the end disk. The contraction of the soil therefore results in a downward movement, which is measured by the micrometer. In order to tell just when the micrometer comes in contact with the end of the follower at *C* an electrical contact device is used. One terminal of a battery is connected through an electric bell to *F*. When *M* makes the metallic connection at *C*, the circuit is closed and the bell rings. Instead of the bell the figure shows an arrangement *T* in which the two bare terminals are held at a short distance apart. By placing these two wires on the tongue, the instant of contact at *C* may be detected by a sharp acrid taste. This device is even more delicate and satisfactory than the bell. The contact can be determined with such precision that the readings taken at the same time show no variation within the limits of the micrometer used. The micrometer scale is held firmly in place by means of a screw clamp. The wooden support is sawed in such a way that the micrometer scale is slipped into position and a screw clamp pinches the two sections of the wooden support. The part of the apparatus consisting of the soil column and its follower can be lifted from the wooden supports without in any way affecting the soil sample. A different soil sample can be placed in position and measured by the same micrometer. At each measurement this movable part comes into the same position, for it is brought down firmly against the end block *B*. Since the wooden vertical supports are cut V shaped, the half-round section of brass tubing fits snugly into place.

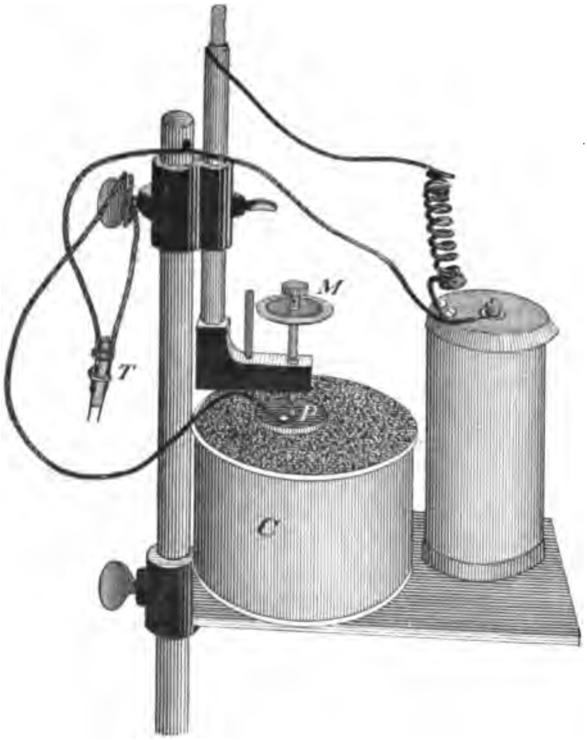

FIG. 33.—Apparatus for micrometer method of measuring changes in soil volumes.

This method has proved well suited to soils having the power to retain the form of the cylindrical soil column irrespective of the moisture content. Some soils, however, can not be successfully handled in this way, either because when wet they become incoherent and do not retain their form or because when dry they crumble. The method is not well suited for continued observations on wetting and drying of the same soil sample, because, as has been pointed out in a previous chapter, the volume changes tend to cause cracking of the soil; these cracks become points of weakness and in time cause the breaking down of the soil column.

Micrometer method.

In order to get around the difficulties just described the "micrometer method" was devised, in which the soil sample is better supported, being held in a cup. The form of apparatus is shown in figure 33. The soil sample is contained in a cup *C*, which has a perforated bottom through which the soil may be wetted. This cup rests directly on the metal table of an adjustable stand, to which the micrometer screw is also attached. This method of support has a distinct advantage, since there is little possibility of the table and micrometer changing their relative positions and thus affecting the results. The variation in the height of the soil surface is measured by means of the micrometer screw *M*. A brass plate *P* with a projecting short vertical shaft rests on the surface of the soil. The micrometer point is brought just into contact with the top of the shaft. The contact is determined in the same manner as described in the preceding method. In order to obtain a good electrical contact with the plate *P* without disturbing its position in any way, a drop of mercury is held in a depression drilled into the surface of the brass.

This method also permits measurements being made on a number of samples, since the cup *C* can be removed from the table and another cup inserted in its place without displacing the micrometer. The moisture content of the soil sample corresponding to the time of measurement is determined in both this and the soil column method by directly weighing the supporting dish, the dry soil equivalent being determined when the sample is first prepared. Although the micrometer screw used in this method measures to 0.0001 centimeter, measurements were ordinarily made only to 0.001. On account of the electrical conductivity of the moist soil and since the cup rests on the metallic table it is necessary to insulate the brass plate *P* from the soil. This is done by fastening a hard rubber disk to the underside of the plate. The same result can, of course, be obtained by insulating the cup *C* from the stand. In this method the amount of surface exposed to evaporation is not so large as in the soil column method, so that the time required for a series of measurements is somewhat longer. Because of the better support of the soil column this method is applicable to almost any soil and quite independent of errors due to a defective soil column. In any future work it would be well to use larger dishes; this would tend to reduce to a minimum any errors due to adhesion between the soil and the cup. A deeper dish may profitably be used, thus giving a larger linear change, but it must be not deep enough to cause a large difference in moisture content between the lower and upper soil layers.

Cathetometer method.

The cathetometer method closely resembles the micrometer method. The soil is contained in a similar dish and the up and down movements of a point fastened to a brass disk are measured by means of a cathetometer instead of a micrometer. This method is valuable as a check method, showing that the same results are obtained irrespective of the method used. It offers no particular advantage over the micrometer method and possesses some disadvantages. Since the cathetometer and the soil are placed several feet apart, they have no support in common, and a change of pressure on the floor may cause a variation in the level and a corresponding error in the readings obtained. Sighting the cross hairs of the cathetometer telescope on the point does not permit the same accuracy of reading as in case of the micrometer with the electric contact method. The finest graduations on the cathetometer used were 0.01 centimeter. This, added to the difficulty of reading mentioned above, made very accurate results impossible. This method might be improved by having the apparatus set up on a firm foundation, having better sighting device, larger dishes, etc., but the only advantage it can then offer over the micrometer method is that the plate on the soil surface would not be subject to any disturbing external pressure, such as might possibly be caused by the micrometer screw.

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Issued April 17, 1908.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF SOILS—BULLETIN No. 51.

MILTON WHITNEY, Chief

ABSORPTION OF VAPORS AND GASES BY SOILS.

BY

HARRISON E. PATTEN AND FRANCIS E. GALLAGHER.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1908.

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LETTER OF TRANSMITTAL

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., January 14, 1908.

Sir: I have the honor to transmit the manuscript of a technical article entitled "Absorption of Vapors and Gases by Soils," by Messrs. Harrison E. Patten and Francis E. Gallagher. It contains a historical review of the subject, together with experimental studies on the conditions which determine the quantity and rate of gaseous absorption by soils.

The article gives much valuable information which should be made available to the public. In accordance with your suggestion it has been gone over carefully with Assistant Secretary Hays, who authorizes me to state that he concurs in my recommendation for its publication.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

In the continuation of the studies on absorption which have been carried on in this Bureau, it has been deemed desirable to direct attention especially to the absorption of gases by soils, and the present bulletin contains a description of certain special studies on this subject by Messrs. Patten and Gallagher.

That soils have a high absorptive power for gases, and show a direct selective absorption from gas mixtures as well as from liquid solutions, has long been known, and this fact has generally been recognized as having an important agricultural and geological significance. But up to the present it can not be said that agricultural investigators have given the question the consideration which its practical importance warrants.

In the present bulletin the absorption of the principal gases by various types of soils and the rate at which such absorption takes place have been brought out in such a manner that practical workers in soil problems will be able to use the results to advantage. Special significance must be attached to the absorption of water vapor, and in this bulletin the principal facts now known from the investigations of former workers or of the authors of the bulletin themselves are brought together in such shape that they are available not only for practical workers, but for the further investigation of scientific workers.

The relation between the absorption of water vapor on the one hand and the evaporation of water from that soil has been carefully investigated, and the laws controlling it have been clearly brought out; and the influence of soluble materials contained in the soil as affecting these laws has been shown. The significance of cultural methods as affecting either the absorption of water vapor or its evaporation has been shown. And finally, the important practical fact has been established that the wilting point—or that water content of the soil at which plants can no longer thrive and which has been shown elsewhere to be a physical factor of the soil—marks a water content higher than that which the soil can attain by direct absorption from a humid atmosphere, even though this latter be maintained at the point of saturation.

The laws governing the absorption of other gases or vapors appear in general to be very similar to those governing the absorption of water vapor, and it may now be safely claimed that the broad subject of absorption of vapors by soils has been brought to a satisfactory state as regards not only our theoretical knowledge of the principles involved and their importance to practical agriculture, but also as they bear upon the practical methods of control.

FRANK K. CAMERON.

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ABSORPTION OF VAPORS AND GASES BY SOILS.

PREVIOUS WORK.

INTRODUCTION.

It is well known that charcoal absorbs enormous volumes of gases from putrefying animal matter, and the similar power of soils to take up odors from excreta has been utilized from the earliest times.

The term *absorption* includes adsorption upon the surface, possible penetration of vapor into the solid, and retention of liquid in the angles formed between adjoining particles. A short review of the development of our knowledge of gaseous absorption is helpful here in bringing to mind the experimental facts and the varying explanations offered in connection therewith.

ABSORPTION OF GASES.

Fontana in 1777 established the fact that numerous porous bodies retain gases upon their internal surface, but did not deduce regularities from his data.

Morozzo, Rouppe, and Norden[a] confirmed his observations in 1800, but de Saussure,[b] during 1812 to 1814, was the first to investigate this field extensively. He heated his absorbent material to redness before using, to expel residual gases, and then subjected the weighed absorbent to the action of a gas, under known temperature and pressure conditions. He drew the following conclusions: (1) The porous bodies investigated absorb gases; (2) the degree of absorption varies with the form and magnitude of the pores; (3) different substances possess a different absorption capacity; (4) the same substance absorbs different quantities of different gases; (5) easily condensed gases are in general absorbed more easily; (6) absorption decreases as temperature increases; (7) at higher pressure more gas is absorbed than at lower pressure; (8) heat is evolved during the process of absorption.

To these fundamental observations Smith[c] adds: (1) Charcoal exercises a selective absorption toward mixtures of gases; for a considerable time oxygen alone is absorbed from air; (2) charcoal saturated with nitrogen and then placed in other gases first gives up a part of the nitrogen before absorbing the second gas; (3) charcoal saturated with oxygen does not give up the gas, either upon warming or treatment with boiling water, but under these conditions carbon dioxide is evolved rather than oxygen.

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[a] O. Lehmann, Molekular-physik, II part, 83.

[b] Ann. Phys. Gilbert, 47, 113 (1814).

[c] Ann. Chem., Suppl. 2, 262 (1862-1863).

Stenhouse,[a] too, has studied the absorption of gases by charcoal made from various materials; his figures, given in Table I, represent the number of cubic centimeters of gas absorbed by 1 gram of charcoal. Wood charcoal shows a higher absorption for the gases used than does peat or animal charcoal, with the exception of hydrochloric acid gas, which is taken up in greater volume by peat.

TABLE I. *Absorption of gases by charcoal, according to Stenhouse.*

Gas.	Kind of charcoal.		
	Wood.	Peat.	Animal.
	C. c.	*C. c.*	*C. c.*
Ammonia	98.5	96.0	43.5
Hydrochloric acid	45.0	60.0	....
Sulphurous	32.5	27.5	17.5
Carbonic acid	14.0	10.0	5.0
Oxygen	0.8	0.6	0.5

Dewar[b] has found that charcoal and lampblack are nearly equal in absorbing power for gases at the temperature of liquid air, and that graphite is only one-fourth as good an absorbent.

ABSORPTION OF AIR.

Reichardt and Blumtritt[c] showed that nitrogen is absorbed to a much greater extent by soils and soil constitutents than is oxygen and that each gas is retained to a different degree by different substances—a clear indication of the selective power which solids and gases mutually exert in absorption reactions.

ABSORPTION OF WATER VAPOR BY SOILS.

When a soil is saturated with water by rain, part of the water percolates away to lower levels, and another part of the water evaporates from the surface.

With a view to correlating the capacity of soils to resist drying out, with their composition and with their productiveness, Schübler[d] determined the water vapor absorbed by various soils and soil constitutents from a nearly saturated atmosphere during 24 hours. This absorption process is evidently the reverse of drying out, but gives a measure of the speed with which a dry soil takes up the first portions of water vapor, and this speed is clearly an indication of the strength with which the water is held by each soil. Thus, he found that 1,000 parts of soil absorbed parts of water as follows: Quartz sand, coarse, 0; gypsum, 1; calcareous sand, 3; plow land, 23; clay soil (60 per cent clay), 28; slaty marl, 33; loam, 35; fine carbonate of lime, 35; heavy clay soil (80 per cent clay), 41; garden mold (7 per cent humus), 52; pure clay, 49; carbonate of magnesia (fine powder), 82; humus, 120.

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[a] Cited by Johnson, How Crops Feed, p. 160.

[b] Chem. News, **94**, 174 (1906); Proc. Roy. Soc., **74**, 130 (1904).

[c] Jour. prakt. Chem., **98**, 476 (1866).

[d] Cited by Johnson, How Crops Feed, pp. 161-162, 1870.

Similarly Davy[a] gives the quantity of moisture taken up during one hour exposure to the air by soils which had been dried at 212° F. as follows, in parts of water per 1,000 parts of soil: Sterile soil of Bagshot heath, 3; coarse sand, 8; fine sand, 11; soil from Mercy, Essex, 13; very fertile alluvium, Somersetshire, 16; extremely fertile soil of Ormiston, East Lothian, 18.

From these results it may be concluded that the absorptive capacity of soil for water vapor is generally higher the finer the texture of the soil and the greater its content of humus. It appears, too, that productive soils have a very considerable capacity for water vapor, while the poor soils range much lower.

Regarding the effect of temperature upon the quantity of water vapor absorbed, Knop[a] has shown that at higher temperature the absorption is very considerably decreased. A sandy soil from Moeckern, Saxony, absorbed in parts of water per 1,000 parts of soil the following quantities of moisture: At 55° F., 13; at 66°, 11.9; at 77°, 10.2; at 88°, 8.7.

The experiments of Ammon[b] likewise show that the absorption of water vapor by soil constituents decreases as the temperature rises. The relative absorption at any one temperature of the substances used decreases in the order, ferric hydroxide, humus, kaolin, calcium carbonate, gypsum.

Von Dobeneck[c] has studied in great detail the conditions which determine the absorption of water vapor and gases in general by various soil constituents and admixtures of the same, with the following results: (1) The absorption is greater the finer the particles of the solid; but this increase is not directly proportional to the increase in surface, since large grains absorb relatively more gas than would be expected from the surface exposed. It should be remembered, however, that great error is introduced when the surface of a powder is calculated from the average diameter of its granules. (2) He found that adsorption and hygroscopic retention of moisture upon surfaces, which were then looked upon as different, are subject to the same controlling conditions. (3) The different soil constituents all possess a considerable absorption capacity, but gases are absorbed to a different degree by each solid substance. (4) Mixtures of these soil constituents absorb gases additively; that is, each soil material exerts its absorptive effect independently of the rest of the soil about it. (5) Absorption decreases with rise in temperature and is very nearly proportional to the reciprocal of the partial pressure. (6) For atmospheres of the same relative humidity, the temperature has little effect upon the mass of water absorbed; the absorption increases with increasing relative humidity, and at 20° C. the rise in absorption for equal per cent increments in the relative humidity is greater the nearer the interval lies to the point of saturation (100 per cent humidity). (7) Soil constituents moistened with water absorb gases in greater quantity than the same mass of water alone.

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[a] Cited by Johnson, How Crops Feed, pp. 161–162, 1870.

[b] Forsch. Agr.-Phys., **2**, 36 (1879).

[c] Forsch. Agr.-Phys., **15**, 163 (1892).

Van Bemmelen[a] has determined the absorption of water vapor by soils and inorganic oxides, especially such as yield gelatinous hydrates with water, with reference to (1) the influence of original water contained in the soil or solid oxide upon the quantity of water it can yet absorb; (2) the effect of vapor pressure upon absorption and liberation of moisture; (3) the structure and history of the oxide as related to its absorptive power. He used the oxides, SiO_2, SnO_2, MnO_2, Al_2O_3, Fe_2O_3, Cr_2O_3, BeO, MgO, and CuO and various soils. His results in general indicate that the absorption of water vapor increases with the vapor pressure, but is not simply proportional to it; that the fineness of the grains of a partially hydrated oxide has little influence upon its absorption—an effect to be expected where imbibition takes place; that the moist oxides expand as more water is absorbed and contract as this water evaporates from them in an atmosphere of lower vapor pressure; that some oxides form a translucent jelly when they contain a certain quantity of water, and this translucence indicates that the jelly is made up of fine cells. He concludes that the existence of definite chemical hydrates in these noncrystalline jellies is as yet undemonstrated and extremely improbable.

Van Bemmelen's reason for so thoroughly investigating these gelatinous inorganic hydrates is that much of the absorptive power of a soil is due to their presence, occasioned by the disintegration of minerals subject to weathering. His results on the absorption of water vapor by soils are similar to those obtained with these inorganic oxides, and agree in general with the results of earlier investigators. Each soil shows its own peculiar power of absorbing water vapor—the finer the soil grains the greater the absorption; the presence of individual soil constituents of high absorptive power, of course, raises the absorption in proportion to the amount of each in the soil.

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[a] Zeit. anorg. Chem., **5**, 467 (1893); Ber. deutsch. chem. Ges., **13**, 1467 (1880); Jour. prakt. Chem., **23**, 324, 379 (1881); **26**, 227 (1882); Rec. Trav. Chim. Pays.-Bas, **7**, 1 (1888); Jour. prakt. Chem., **46**, 497 (1892); Zeit. anorg. Chem., **18**, 122 (1898); **20**, 185 (1899); **23**, 111–321 (1900); Sitzungsber. d. K. Akad. d. Wiss., Amsterdam, Nov. 26, 1902; Arch. Néel. (2), **10**, 267 (1906). See also Cross, On the Reformation of Hydrates, Jahresb., 1879, 179; also, Spring and Lucion, Zeit. anorg. Chem., **2**, 195 (1892).

According to Hilgard,[a] the hygroscopic moisture of a soil may vary from 2.48 per cent to 21 per cent, depending upon its composition. He has criticized the experiments of Schübler, Knop, and others, who found that absorption of water vapor decreases with rise in temperature. Hilgard finds that exactly the reverse is the case; soils exposed to an atmosphere saturated with water vapor absorb more moisture at high temperature than at low.

An attempt to discriminate between moisture held by a powder as "hygroscopic moisture" and water in the capillary spaces meets with difficulty.[b] We have no sharp experimental method of ascertaining what fraction of the water is retained on the surfaces of the grains. This is especially so as an even distribution of moisture throughout the powder is hard to secure, and failing of this the powder is balled together and holds part of the liquid in its capillary spaces between the grains.

Briggs[c] determined the quantity of water vapor absorbed by quartz grains of various degrees of fineness, and from the mechanical analysis of each powder calculated the surface presented, and thus found the thickness of the layer of adsorbed water. Assuming the density of the film as uniform and equal to unity and postulating an even distribution of the water over the entire surface, the maximum thickness obtained was 2.66×10^{-6} cm. in an atmosphere within 1 per cent of saturation at 30° C. He concludes that the adsorption is not due to soluble bodies present upon the surface of the quartz, as Warburg and Ihmori have suggested, but to the mutual attraction of quartz and water.

Parks[d] calculates the thickness of the water film upon glass wool as 13.3×10^{-6} at 15° C. Trouton[e] and O. Masson and E. S. Richards[f] have carefully determined the conditions under which cotton absorbs moisture. Trouton suggests that the water vapor is condensed to liquid upon the surface of the cotton. Masson and Richards find that cotton containing a definite proportion of moisture resembles an aqueous solution in that it exercises a vapor pressure which is at different temperatures a constant fraction of that of pure water.

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[a] "Soils," pp. 196, 198 (1906).

[b] Soyaka, Forsch. Agr.-Phys., 8, 1 (1885); Whitney, Agricultural Science, **8**, 199 (1889); Katao, Ueber die Wasserbewegung in Boden, Bul. Col. Agr., Imp. Univ. Tokyo, Vol. 3, No. 1 (1897); Briggs, Bul. No. 10, U. S. Dept. of Agr., Division of Soils (1897).

[c] Jour. Phys. Chem., **9**, 617 (1905).

[d] Phil. Mag. (6) **5**, 519 (1903); also (6) **4**, 240 (1902).

[e] Proc. Roy. Soc. London, **77**, Ser. A, 292 (1906).

[f] Ibid., **78**, Ser. A, 412–429 (1906).

In this connection it is interesting to note that Bunsen[a] found that glass fiber continued to give up moisture on heating until a temperature of 503° C. was reached; similarly, Day and Allen[b] state that a temperature of 600° to 800° C. (a low red heat) is required to remove hygroscopic moisture from minerals. From the fact that moisture is retained upon the surface of these substances at high temperature it may be inferred that the attraction between the substance and water is greater than the vapor pressure, which at such temperatures amounts to hundreds of atmospheres.

ABSORPTION OF WATER VAPOR.

STATEMENT OF THE PROBLEM.

The general problem before us is to find the relation of climatic humidity to soils. In nature a system is rarely in a state of equilibrium, and more or less rapid changes in the distribution of the constituents are in progress. Still, in the present instance, definite laboratory conditions for the equilibrium between soil moisture and water vapor in the air above it will afford a very fair approximation to field conditions, and by taking measurements upon the rate of approach to equilibrium we also secure an insight into the nature and rate of change in soil moisture during evaporation or absorption when sudden climatic changes disturb the approximate equilibrium between atmospheric moisture and soil moisture. Such displacement of equilibrium may be due to currents of air bringing a more or less humid atmosphere from a distance, or to heat changes accompanied by precipitation on cooling, or greater saturation capacity of the air for water on heating.

The first variation—change in humidity—may be experimentally reproduced by placing several equal portions of a soil of known moisture content in desiccators whose individual atmospheric humidity is maintained practically constant by sulphuric acid, differing in strength for each desiccator and thus giving a range of humidity from the very low partial pressure of concentrated acid to the vapor pressure of water at the temperature chosen for the experiments.

The second source of variation—heat changes—may be studied by running equilibrium experiments similar to those just described, but at different temperatures, and comparing the quantities of moisture in soil and in vapor above it at each of these temperatures.

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[a] Ann. Phys., **24**, 321 (1885).

[b] Pub. Carnegie Inst. of Washington, No. 31, pp. 56-57; Am. Jour. Sci. (4), **19**, 93 (1905).

EVAPORATION STUDIES.

Experimental methods.

The evaporation of water from soils was determined under different degrees of humidity, secured by maintaining the soils in small weighing bottles in desiccators containing sulphuric acid in varying concentration. Quantitative preliminary work showed the need of accurate temperature control; consequently the experiments here described were carried out in a double-walled air thermostat heated by incandescent electric lights, the current being controlled by a Geer thermoregulator [a] and the air circulated by an electric fan. (The temperature was recorded, when desired, by a thermograph. The temperature could thus be held constant and within 0.1° C. for days.)

Diffusion constant for the desiccators.

As regards the diffusion of water vapor from the soil in the weighing bottle through the atmosphere of the desiccator down to the surface of the sulphuric acid, it may be stated that in general this takes place at a very constant rate. This constancy will be evident from an inspection of the curves given in figures 1, 2, and 3, for the evaporation of soils in atmospheres of different degrees of humidity. As may be expected, these curves are linear during the time when evaporation is taking place from the larger soil tubes, but when the soil moisture begins to evaporate from the finer capillary spaces, the rate of evaporation, and consequently the diffusion constant itself, changes as evaporation proceeds. A variation in the value of this diffusion constant may also be due to a slight difference in the size of the mouths of the weighing bottles.

Experimental data.

The rate of approach to equilibrium of quartz flour, Podunk fine sandy loam, and Sea Island cotton soils over water and over sulphuric acid of different strengths at 25° C. is given in Tables II, III, and IV, respectively. The upper section of each table shows the loss of water from a wet soil as the evaporation proceeds, while the lower section gives the absorption by the same soil in dry condition under the same conditions of temperature and humidity. Thus if sufficient time be given, the same percentage of moisture will be found in the soil regardless of its previous moisture content; i. e., equilibrium is approached from both the wet side and the dry side. At the head of each column in the tables is given the strength of sulphuric acid expressed in percentage by weight and the corresponding partial pressure of water vapor in millimeters of mercury.[b] The evaporation data from the upper half of Tables II, III, and IV are plotted in figures 1, 2, and 3, for quartz, Podunk, and Sea Island soils, respectively, ordinates being percentage moisture in the soil reckoned upon its dry weight, and abscissas time in days.

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[a] Jour. Phys. Chem., 6, 85 (1902).

[b] Landolt and Börnstein, Tabellen.

TABLE II.—*Change in moisture content of quartz flour exposed to atmospheres of different humidity at 25° C.*

MOIST SOIL.

Strength of sulphuric acid, with equivalent partial pressure of water vapor.								Water alone.	
94 per cent = 0.10 mm.		55.4 per cent = 6.0 mm.		42.55 per cent = 12 mm.		29.84 per cent = 17.9 mm.		23.55 mm.	
Period.	Moisture content.	Period.	Moisture content.	Period.	Moisture content.	Period.	Moisture content.	Period.	Moisture content.
Days.	*Per cent.*	*Days.*	*Per cent.*	*Days.*	*Per cent.*	*Days.*	*Per cent.*	*Days.*	*Per cent.*
0.00	30.00	0.00	30.00	0.00	30.00	0.00	30.00	0.00	30.0
.167	29.40	1.02	27.80	1.04	28.50	1.04	29.20	1.01	29.9
1.00	26.30	2.11	25.40	2.10	27.20	2.11	28.50	2.11	29.8
2.08	23.10	3.08	23.40	3.08	25.80	3.09	27.80	3.04	29.7
3.08	19.80	4.00	21.60	4.04	24.60	4.04	27.20	6.04	29.5
4.00	16.80	8.00	13.90	8.00	20.00	8.00	24.80	13.00	29.3
5.15	13.40	10.10	9.80	13.00	13.80	13.00	22.00	27.00	28.6
6.04	9.80	13.00	4.10	17.00	9.50	21.20	17.70	55.00	28.5
8.02	4.40	17.00	.10	19.20	6.90	23.00	14.30	97.00	25.4
9.05	1.90	33.00	.09	23.00	2.80	33.00	11.00		
9.87	.50			25.00	1.20	38.00	8.20		
10.13	.10			26.00	.20	46.00	4.30		
11.16	.10			27.00	.12	52.00	1.30		
17.00	.07			30.00	.12	97.00	.12		
33.00	.07			33.00	.11				

DRY SOIL.

0.0	0.10	0.0	0.1	0.0	0.10	0.0	0.10	0.0	0.10
1.0	.10	1.0	.1	1.0	.10	1.0	.10	1.0	.20
13.0	.08	33.0	.1	33.0	.11	3.0	.10	2.0	.20
33.0	.07					97.0	.12	3.0	.20
								6.0	.30
								13.0	.30
								27.0	.40
								55.0	.42
								97.0	.61

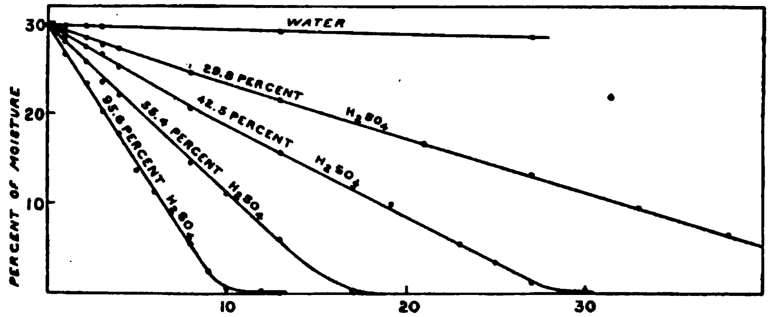

FIG. 1.—Curves for quartz flour, showing effect of humidity upon rate of evaporation.

TABLE III.—*Change in moisture content of Podunk fine sandy loam soil exposed to atmospheres of different humidity at 25° C.*

MOIST SOIL.

Strength of sulphuric acid, with equivalent partial pressure of water vapor.								Water alone.	
95.6 per cent =0.10 mm.		55.4 per cent =6.0 mm.		42.55 per cent =12 mm.		29.84 per cent =17.9 mm.		23.55 mm.	
Period.	Moisture content.	Period.	Moisture content.	Period.	Moisture content.	Period.	Moisture content.	Period.	Moisture content.
Days.	*Per cent.*	*Days.*	*Per cent.*	*Days.*	*Per cent.*	*Days.*	*Per cent.*	*Days.*	*Per cent.*
0.00	30.00	0.00	30.0	0.00	30.00	0.00	30.00	0.00	30.0
.167	29.50	1.02	28.1	1.04	28.70	1.04	29.20	1.01	29.9
1.00	26.70	2.11	25.9	2.11	27.50	2.11	28.50	2.12	29.8
2.09	23.30	3.08	23.8	3.09	26.80	3.11	27.80	3.12	29.7
3.00	20.30	4.00	22.1	4.04	25.20	4.04	27.20	6.04	29.5
4.00	17.90	8.00	14.8	8.00	20.60	8.00	24.60	13.00	29.2
5.15	13.90	9.10	11.2	13.00	15.70	13.00	21.60	27.00	28.6
6.04	11.50	13.00	6.0	17.00	11.90	21.20	16.80	55.00	27.5
8.02	5.60	17.00	.4	19.20	9.80	23.00	13.30	97.00	26.5
9.05	2.50	33.00	.3	23.00	5.70	33.00	9.70		
9.87	.70			25.00	3.50	38.00	6.50		
10.13	.40			27.00	1.10	46.00	2.50		
11.16	.30			30.00	.40	52.00	.60		
17.00	.13			33.00	.43	97.00	.51		
33.00	.04								

DRY SOIL.

0.0	0.30	0.0	0.3	0 0	0.3	0.0	0.30	1.01	0.30
1.0	.30	1.0	.4	1.0	.4	1.0	.50	2.12	.70
13.0	.16	10.0	.4	33.0	.4	3.0	.51	3.12	.70
17.0	.13	33.0	.3			97.0	.48	6.04	.80
21.0	03							13.00	.90
33.0	.02							27.00	1.00
								55.00	1.10
								97.00	1.16
									1.24

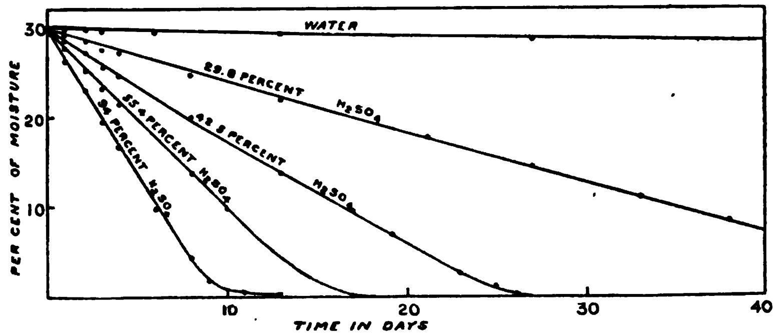

FIG. 2.—Curves for Podunk soil, showing effect of humidity upon rate of evaporation.

TABLE IV.—*Change in moisture content of Sea Island cotton soil exposed to atmospheres of different humidity at 25° C.*

MOIST SOIL.

Strength of sulphuric acid, with equivalent partial pressure of water vapor.								Water alone.	
94 per cent =0.10 mm.		55.4 per cent =6.0 mm.		42.55 per cent =12 mm.		29.84 per cent =17.9 mm.		23.55 mm.	
Period.	Moisture content.	Period.	Moisture content.	Period.	Moisture content.	Period.	Moisture content.	Period.	Moisture content.
Days.	*Per cent.*	*Days.*	*Per cent.*	*Days.*	*Per cent.*	*Days.*	*Per cent.*	*Days.*	*Per cent.*
0.00	55.00	0.00	55.0	0.00	55.0	0.00	55.00	0.00	55.0
.167	54.20	1.01	52.9	1.04	53.2	1.03	54.10	1.10	54.8
.96	51.60	2.10	50.5	2.09	51.4	2.11	53.30	2.11	54.7
2.08	48.60	3.08	48.4	3.08	49.8	3.09	52.10	3.14	54.6
3.08	45.60	4.00	46.5	4.04	48.3	4.04	51.90	6.04	54.3
4.00	43.20	8.00	37.4	8.00	42.1	8.00	49.30	8.00	54.0
5.15	40.10	10.10	33.1	13.00	35.0	13.00	46.30	10.10	53.9
6.04	37.50	13.00	27.6	17.00	29.4	21.20	41.20	13.00	53.7
8.02	30.00	17.00	17.6	19.20	26.1	27.00	37.70	27.00	53.1
9.05	27.00	19.20	11.2	23.00	20.4	33.00	34.10	55.00	49.2
9.87	24.00	23.00	4.6	27.00	15.0	46.00	25.50	97.00	48.5
11.16	17.90	25 00	3.5	30.00	10.5	52.00	21.52		
12.08	13.70	27.00	3.1	33.00	6.6	97.00	6.08		
13.05	9.20	30.00	2.9	38.00	4.7				
14.00	6.40	33.00	2.9	46.00	4.4				
17.00	2.10	52.00	2.8	52.00	4.2				
21.00	.98								
33.00	.34								

DRY SOIL.

0.0	4.40	0.0	4.4	0.0	4.4	0.0	4.4	0.00	4.4
1.0	4.10	1.0	4.6	1.0	4.7	1.0	4.9	1.01	5.1
13.0	2.90	13.0	4.8	13.0	4.9	3.0	5.4	2.13	5.6
17.0	1.70	33.0	2.9	21.0	4.1	4.0	5.5	3.12	5.9
21.0	1.00	52.0	2.8			13.0	5.9	4.04	6.1
33.0	.47					21.0	6.0	6.00	6.6
						97.0	5.6	8.00	6.8
								10.10	7.2
								13.00	7.6
								27 00	8.6
								55.00	9.2
								97.00	9.7

Discussion.

Evaporation from soils under different conditions of humidity in general proceeds regularly, as shown by the above curves, which are similar in form. The curves for Sea Island soil over 55.4 per cent sulphuric acid and over the concentrated acid (fig. 3) are displaced to the left in their lower portions. This effect is almost certainly due to the fact that the samples of quartz, Sea Island, and Podunk soils were run in the same desiccator. The latter two soils holding less water, reached the dry state first, and when they no longer gave up water to the surrounding atmosphere the rate of evaporation for Sea Island cotton soil increased, thus producing the displacement in the curve. This observation emphasizes the necessity of closely regulating the conditions for evaporation studies.

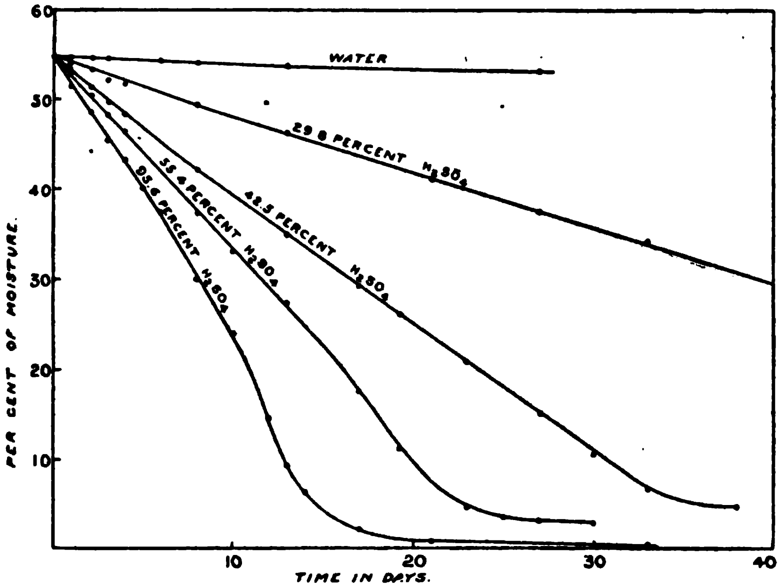

FIG. 3.—Curves for Sea Island cotton soil, showing effect of humidity upon rate of evaporation.

The influence of the presence of organic matter in a soil is shown by a comparison of the evaporation curves for quartz, Podunk, and Sea Island soils over concentrated sulphuric acid. The presence of organic matter in Sea Island soil increases its water-holding power some 25 per cent above that of quartz or Podunk soil, but it does not decrease the rate of evaporation, for the Sea Island curves are very nearly parallel to those for Podunk fine sandy loam and for quartz.

The foregoing study is important in that it gives a valid basis for applying the experimental results determined for one humidity condition to any other humidity condition. Because of the high rate of evaporation and slow change in vapor pressure of the acid, it is preferable to use concentrated sulphuric acid in evaporation studies. Results thus obtained may be confidently used for general application.

The relation of the length of time required for a soil to dry out to the atmospheric humidity is of great agricultural interest. Equal changes in humidity correspond to very unequal periods required for a soil to dry. Thus, for quartz, 60 days would be required to reach an air-dry condition with an atmospheric humidity of 75 per cent: 26 days with 50 per cent humidity; 16 days with 25 per cent humidity, and the proportionately long period of 10 days with 1 per cent humidity.

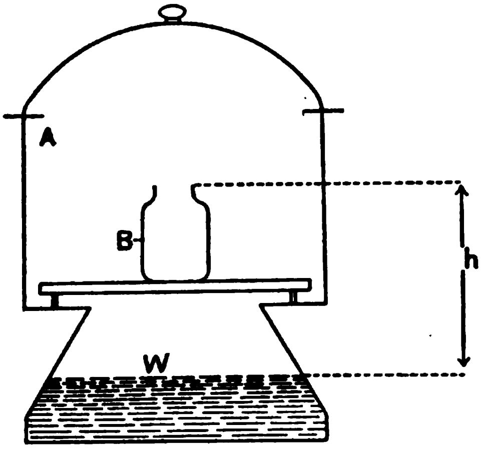

FIG. 4.—Drawing of desiccator containing soil sample.

The rate of evaporation curves show, too, that wet soil in an atmosphere saturated with water vapor slowly loses weight. This loss may be due to several disturbing influences.

There is a slight difference in the vapor pressure of the water in the bottle B and the water W, caused by the weight of a column of vapor of height *h* (see fig. 4). $P_b - P_w = hd$, where P_b and P_w are the vapor pressures at the level in the bottle and at the lower water surface W, respectively, and *d* is the density of the vapor. Although this value is very small, it is theoretically of interest and might enter into calculation when the time factor is large.

Small changes in temperature would cause loss of water from the weighing bottle containing moist soil. If the temperature rises a little this will first affect the desiccator near the outside wall, at A, figure 4. The increase in temperature momentarily reduces the relative humidity, thus disturbing the equilibrium. In order to restore equilibrium water vapor moves from the interior of the desiccator near B toward A. This produces at the same time evaporation of the water in B and of the water at W in the bottom of the desiccator. If a slight drop in the temperature within the thermostat now takes place cooling will first occur at A, followed by supersaturation and finally by condensation of moisture at A until equilibrium is again established. This cooling, however, will not produce a condensation upon the surface of the soil equal in amount to the loss by evaporation due to rise in temperature. Thus a slow loss of water from soil will result.

The thermostat was heated by an incandescent electric lamp, consequently a black soil might absorb sufficient radiant energy to maintain its temperature slightly above that of the surrounding medium. The vapor pressure of the warmer soil moisture would be higher, and a distillation of water from B to W would result.

Opening the desiccator for estimation of the moisture in soil would reduce the humidity and cause evaporation from the soil when replaced after weighing.

ABSORPTION STUDIES.

Experimental data.

The absorption of moisture by air-dry soils in an atmosphere saturated with water vapor is shown by the data given in Tables II, III, and IV for quartz, Podunk fine sandy loam, and Sea Island cotton soils at 25° C. As stated above, these experiments were carried out with weighing bottles placed in a desiccator. A parallel set of experiments using shallow aluminum dishes showed that the dishes do not give so great gain in moisture as is obtained when weighing bottles are used. The three soils used here were in air-dry condition at the start; their moisture content in percentage is given in Tables II, III, and IV.

A set of absorption experiments was carried out, using other soils and soil separates which had been heated to constant weight at 110° C. and then placed in a saturated atmosphere at 28° C. This set was not subjected to such accurate temperature control as those given above, still the curves obtained by plotting gain in moisture against time of absorption are very regular and the data fairly characteristic. The data are given in Table V.

TABLE V.—*Water vapor absorbed by soils from a saturated atmosphere at 28° C.*

Period.	Galveston clay.	Hagers-town loam.	Marshall silt loam.	Norfolk sand.	Quartz.
Days.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	4.699	1.717	1.823	0.169	0.144
2	5.896	2.047	2.220	.220	.203
3	6.504	2.363	2.455	.240	.245
14	8.928	3.152	2.990	.322	.417
19	9.685	3.317	3.160	.334	.420
23	9.779	3.625	3.383	.354	.502
31	10.228	3.974	3.603	.390	.574
34	10.277	4.014	3.611	....	....
37	10.373	4.107	3.713	.416	.625
49	10.841	4.553	4.005	.440	.752
AREA PER GRAM.					
	Sq. cm.	*Sq. cm.*	*Sq. cm.*	*Sq. cm.*	*Sq. cm.*
	3.280	2,270	2,320	300	1,260

Discussion.

At the bottom of Table V is given the area of each soil in square centimeters per gram as calculated from its mechanical analysis. This affords a rough comparison of soil texture with absorptive power, and shows that in a broad way the absorptive power is greater for soils of fine texture, as would be expected. Galveston clay absorbs three times the mass of water vapor that Marshall silt loam takes up, while the calculated area of the clay per gram is not three times greater, but less than a third greater, than for the silt loam.

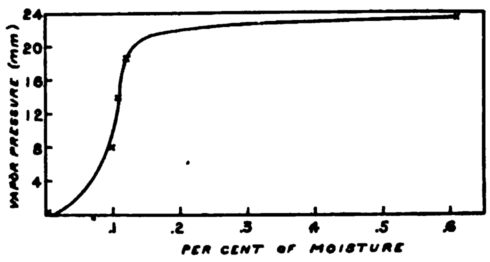

FIG. 5.—Curve showing variation of moisture in quartz flour with increase in atmospheric humidity.

DEPENDENCE OF MOISTURE CONTENT UPON HUMIDITY.

Table VI contains a summary of the equilibrium points already given in Tables II, III, and IV—that is, the percentage of moisture retained by each soil over each strength of sulphuric acid, a quantity which is practically the same as the per centage absorbed by the air-dry soil from air saturated with moisture over the different concentrations of sulphuric acid used. Of course, during the evaporation from the moist soil the sulphuric acid in each desiccator became diluted. In Table VI is given the initial and final strength of each portion of acid and the corresponding partial pressures of water vapor over this acid. Opposite these acid percentages are found the moisture contents of each soil, quartz, Podunk, and Sea Island.

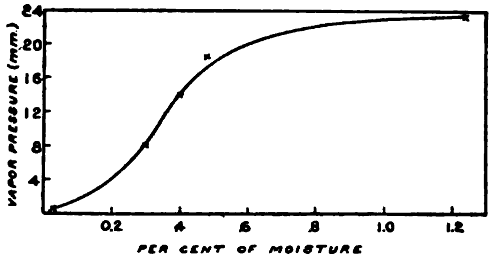

FIG. 6.—Curve showing variation of moisture in Podunk soil with increase in atmospheric humidity.

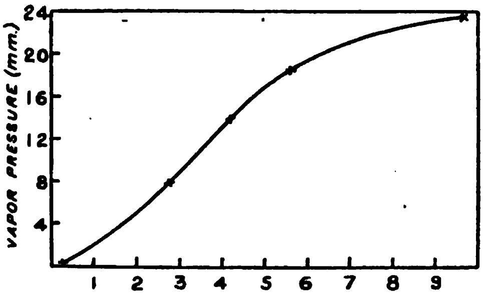

FIG. 7.—Curve showing variation of moisture in Sea Island cotton soil with increase in atmospheric humidity.

In figures 5, 6, and 7 curves are plotted from the data given in Table VI, showing the variation in moisture content of each soil with increasing atmospheric humidity. Ordinates are in partial pressures of water vapor expressed in millimeters of mercury; abscissas percentage of water in the soil.

TABLE VI.—*Variation of moisture content of soil with humidity under equilibrium conditions at 25° C.*

Strength of sulphuric acid.				Quartz.		Podunk.		Sea Island.	
Initial.		Final.		Drying out.	Absorbing moisture.	Drying out.	Absorbing moisture.	Drying out.	Absorbing moisture.
Per cent	*—Mm.*	*Per cent*	*—Mm.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
94.00	0.01	88.3	0.09	0.07	0.07	0.04	0.02	0.34	0.47
55.40	6.00	51.2	8.00	.09	.10	.30	.30	2.80	2.80
42.55	12.00	39.0	14.00	.11	.11	.43	.40	4.20	4.10
29.84	17.90	27.1	18.30	.12	.12	.51	.48	6.08	5.60
Water.	23.50	Water.	23.50	....	.61	....	1.24	....	9.70

The point on each of these curves figures 5, 6, and 7 corresponding to 23.5 mm., the partial pressure of water vapor at 25° C., may be high on account of the "dew point" effect produced by even slight temperature changes, as suggested in the previous discussion.

Because of the wide range through which the moisture content varies, the curve for Sea Island cotton soil in figure 7 is probably the most correctly determined. Owing to its low percentage of absorbed water, errors caused by slight temperature changes are greater relatively for quartz, and its curve in figure 5 is less accurate. These curves in figures 5, 6, and 7 resemble those given by van Bemmelen[a] for the absorption of water vapor by silicic acid at various partial pressures, save that for these soils no certain hysteresis effect is shown. However, we are here dealing with an adsorption effect rather than with imbibition, especially in the case of quartz flour; whereas van Bemmelen's hysteresis effect occurs with the colloidal silicic acid and is due mainly to imbibition; indeed, he gives data showing that the fineness of the silicic acid particles has no marked effect upon the mass of water vapor absorbed.

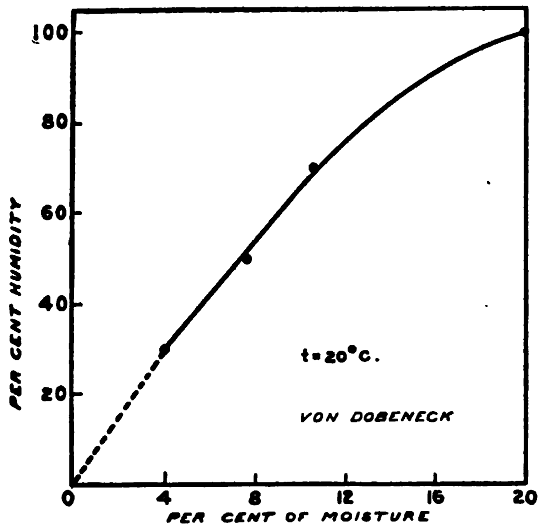

FIG. 8.—Curve showing variation of moisture in humus with increase in atmospheric humidity.

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[a] Zeit. anorg. Chem., 13, 233 (1896-97).

For comparison with this data, von Dobeneck's work upon the absorption of water vapor by humus in atmospheres of different humidity is given in Table VII. The equilibrium points are plotted in figure 8 and give a curve similar in form to that in figure 6 for the Podunk soil.

TABLE VII.—*Change in moisture content of humus submitted to atmospheres of different degrees of humidity at 20° C., according to von Dobeneck.*

Humidity 30 per cent.		Humidity 50 per cent.		Humidity 70 per cent.		Humidity 90 per cent.		Humidity 100 per cent.	
Period.	Moisture absorbed.	Period.	Moisture absorbed.	Period.	Moisture absorbed.	Period.	Moisture absorbed.	Period.	Moisture absorbed.
Days.	*Per cent.*	*Days.*	*Per cent.*	*Days.*	*Per cent.*	*Days.*	*Per cent.*	*Days.*	*Per cent.*
1	1.68	1	[a]4.91	1	[a]8.03	1	[a]10.85	1	[a]16.11
2	2.96	2	5.77	2	8.47	2	11.28	2	16.49
3	3.47	3	6.41	3	8.74	3	11.65	3	16.75
4	3.62	4	6.96	4	9.00	4	12.06	4	16.93
5	3.68	5	7.36	5	9.31	5	12.48	5	17.09
6	3.73	6	7.60	6	9.51	6	12.96	6	17.29
7	3.80	7	7.63	7	9.70	7	13.44	7	17.50
8	3.94	8	7.68	8	9.77	8	13.94	8	17.71
9	3.99	9	7.74	9	9.94	9	14.28	9	17.83
10	4.01	10	7.75	10	10.16	10	14.56	10	17.85
11	4.03	11	7.76	11	10.27	11	14.95	11	17.89
12	4.05	....	....	12	10.32	12	15.24	12	17.90
....	....	....	....	13	10.47	13	15.27	13	17.96
....	....	....	....	14	10.42	14	15.36	14	18.02
....	....	....	....	15	10.48	15	15.44	....	....
....	....	....	....	16	10.54	16	15.49	....	....
....	....	....	....	17	10.57	17	15.55	....	....
....	....	....	....	18	10.58	18	15.59	....	....
....	....	....	....	19	10.59	19	15.63	....	....
....	....	....	....	20	10.58	20	15.67	....	....

[a] The sample of humus after being saturated in an atmosphere of a given degree of humidity was placed in an atmosphere of higher humidity and allowed to reach equilibrium. This process was continued up to an atmosphere of 100 per cent humidity.

ABSORPTION OF OTHER VAPORS.

In Table VIII is given the percentage of toluene ($C_6H_5.CH_3$) vapor absorbed by Galveston, Hagerstown, Marshall, and Norfolk soils and quartz from a saturated atmosphere at 28° C. Similarly, Table IX contains the percentage of ether taken up by the soils at 27° C. from an atmosphere consisting entirely of ether vapor. Comparing these results with those given in Table V it is seen that Galveston clay has the same relative absorptive power for toluene and for water, although the mass of water vapor retained is almost exactly twice that of the toluene. The Hagerstown, Marshall, and Norfolk soils absorb toluene vapor to the extent of slightly less than half the mass of water vapor each soil can take up. Galveston clay absorbs about one-half more ether than water by weight, while the reverse is true of Norfolk sand, and the other two soils take up about the same quantity of ether as of water. Table X gives the absorption of water, ether, and toluene vapors at 28° C. by a soil separate fraction obtained in the mechanical analysis of soils[a] whose grains varied from 0.1 to 0.05 mm. in diameter. Here the absorption of ether vapor is slightly higher than that of water, and the toluene considerably lower. Still the quantities of all three vapors absorbed are of the same order of magnitude.

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[a] See Bul. No. 24, Bureau of Soils, U. S. Dept. Agr. (1904).

TABLE VIII.—*Toluene vapor absorbed by soils from a saturated atmosphere at 28° C.*

Period.	Galveston clay.	Hagers-town loam.	Marshall silt loam.	Norfolk sand.	Quartz.
Hours.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
18.00	2.400	0.860	0.810	0.078	0.112
25.25	2.697	....	.853	.083	....
67.08	3.797	1.367	1.297	.117	.192
139.00	4.467	1.736	1.529	.138	.272
187.00	4.791	1.851	1.615	.167	.285
477.00	5.318	1.866	1.759	.185	.285

TABLE IX.—*Ether vapor absorbed by soils, at 27° C., 575 mm. pressure.*

Period.	Galveston clay.	Hagers-town loam.	Marshall silt loam.	Norfolk sand
Days.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
0.75	4.320	2.625	2.320	0.421
11.75	4.840	3.580	3.070	.459
16.75	5.015	3.82	3.310	.470
28.00	5.760	3.995	3.605	.618
31.00	5.870	4.371	3.895	.618

TABLE X.—*Absorption of water, ether, and toluene vapors by a soil separate (0.1-0.05 mm.), at 28° C.*

Period.	Toluene.	Ether.	Water.
Hours.	*Per cent.*	*Per cent.*	*Per cent.*
17.75	0.264	0.481	0.367
25.50	....	.515	.418
35.00	.343	....	....
42.75	....	.699	.539
106.75	.396	....	....
114.50	....	.763	.609
154.25	.405	....	....
162.00	....	....	.624
352.00	....	....	.718

ABSORPTION OF GASES.

Absorption of air.

Reichardt and Blumtritt[a] recovered the gas absorbed by various soils and soil constituents from the atmosphere and analyzed it to ascertain what proportion of each atmospheric gas was held fixed in the soil. Their results are given in Table XI, and show that nitrogen is absorbed to a much greater extent than oxygen, and that each gas is retained to a different degree by different substances, a clear indication of the selective power which solids and gases mutually exert in absorption.

Dewar[b] has shown that all the inert gases—argon, helium, neon, krypton—can be condensed in charcoal as effectively as ordinary gases at suitable pressure and temperature.

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[a] Jour. prakt. Chem., **98**, 476 (1866).

[b] Proc. Roy. Soc., **74**, 130 (1904).

TABLE XI.—*Absorption of atmospheric gases by various substances, according to Reichardt and Blumtritt.*

Substance.	Gas per 100 grams.	Ratio, by volume.		
		Nitrogen.	Oxygen.	CO_2.
	C. c.	*Per cent.*	*Per cent.*	*Per cent.*
Charcoal, air dry	164	100	0	0
Peat	162	44	5	51
Garden soil	14	65	2	33
$Fe(OH)_3$, air dry	375	26	4	70
Fe_2O_3, ignited	39	83	13	4
$Al(OH)_3$, air dry	69	41	0	59
Alumina, dried at 100° C	11	83	17	0
Clay	33	65	21	14
Clay, moistened	29	60	6	34
River silt	40	68	0	32
Magnesium carbonate	729	64	7	29
Gypsum, pulverized	17	81	19	0

Absorption of oxygen.

In addition to the experiments of de Saussure, Smith, Stenhouse, and Reichardt and Blumtritt, several series of investigations have been carried out upon the absorption of oxygen gas. Joulin,[a] working with ignited charcoal, found that oxygen was so quickly absorbed that measurements on the velocity of absorption were not possible with the means at his command. Baker[b] has shown that a temperature of 450° C. is required to recover the gas from charcoal which has absorbed dry oxygen, and that the gas thus obtained is mainly carbon monoxide, only a little carbon dioxide being formed. Dewar,[c] on the other hand, by using a low-temperature bath of liquid air has succeeded in absorbing in charcoal more oxygen than nitrogen from the atmosphere, and upon warming the charcoal to ordinary room temperature again a large part of this oxygen is liberated, along with nitrogen, thus affording a ready means of obtaining oxygen from air by simply repeating the absorption and liberation process till the oxygen has the desired degree of purity. Richards and Rogers,[d] too, have shown that zinc oxide derived from the nitrate, even when heated to very high temperatures, retains nitrogen and oxygen. Morse and Arbuckle[e] confirmed these results, but found no evidence supporting Richards and Rogers's conclusion that the absorbed oxygen escapes more readily than the nitrogen. The zinc oxide was heated by Morse and Arbuckle to a temperature sufficient to melt cast steel and still retained per gram of oxide some 0.3 c. c. of gas whose composition varied—the nitrogen between 64.32 and 68.18 per cent, and the oxygen correspondingly, while the total volume of occluded gas was very nearly constant for eight different experiments.

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[a] Compt. rend., **90**, 741 (1880).

[b] Jour. Chem. Soc., **51**, 249 (1887).

[c] Chem. News, **94**, 174 (1906).

[d] Proc. Am. Acad., **28**, 200 (1893).

[e] Am. Chem. Jour., **20**, 200 (1898).

Absorption of nitrogen.

The absorption of nitrogen by soils has been studied mostly in connection with the absorption of atmospheric gases. From the work of Reichardt and Blumtritt, cited above, it appears that in general nitrogen is absorbed by soils in greater quantity than oxygen. This fact is especially worthy of note, since the absorption of oxygen and nitrogen from air by water gives a higher ratio of oxygen to nitrogen in the solution than the 1:4 relation which exists in air. The explanation immediately suggested is that oxygen is converted to carbon dioxide in the soil by action of the decomposing organic matter. But the similar high absorptive power of aluminum hydroxide, ferric hydroxide, and magnesium carbonate for nitrogen indicates that this is a real phenomenon, since these substances have no way of masking their true absorptive power for oxygen by converting it chemically to carbon dioxide, as a soil does, or to other oxides. Gypsum, too, preserves the ratio 81:19 of nitrogen to oxygen when it absorbs these gases from the air.

Absorption of carbon dioxide.

The determination of the actual quantity of carbon dioxide taken up by a soil from air is difficult, since the absorbed oxygen acts upon the organic matter in the soil to yield carbon dioxide, and the decaying organic matter itself contains carbon and oxygen which adds still more carbon dioxide to the soil atmosphere. The absorption of carbon dioxide from an atmosphere containing this gas alone can be estimated by the reduction of vapor pressure, by a density determination of the gas, or by determining chemically its weight in a given volume of the gas before and after contact with the soil.

Reichardt and Blumtritt determined the per cent by volume of carbon dioxide absorbed by soils and soil constituents. They showed that it is probable that the oxygen of the absorbed air is converted to CO_2 in the peat; of 162 c. c. gas absorbed from air, 44 per cent appears as nitrogen, 5 per cent as oxygen and 51 per cent as carbon dioxide. A similar relation is seen for the garden soil, moistened clay, and river silt. The ignited ferric oxide and aluminum oxide both show higher absorption of oxygen than the hydrated oxides, and lower absorption of carbon dioxide. This indicates that the absorption of carbon dioxide is dependent to a considerable extent upon the presence of water in the absorbing material, further evidence being afforded by the higher absorption of carbon dioxide by the moist clay.

Scheermesser[a] has stated that the amount of carbon dioxide absorbed by a dry soil is proportional to the amount of ferric oxide present, which would appear to be a generalization based on too few observations. Von Dobeneck[a] gives the carbon dioxide absorbed by soil constituents as follows:

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[a] Inaug.-Diss. Jena, 1871; ref. Chem. Centr., 1871, 462.

TABLE XII.—*Absorption of carbon dioxide by soil constituents according to von Dobeneck.*

Soil constituents, 100 grams.	CO_2 absorbed at—			
	0° C.	10° C.	20° C.	30° C.
	Grams.	*Grams.*	*Grams.*	*Grams.*
Quartz	0.023	0.021	0.023	0.022
Kaolin	.329	.298	.261	.215
Humus	2.501	2.125	1.773	1.479
$Fe(OH)_3$	6.975	5.702	5.054	4.274
$CaCO_3$	.028	.053	.034	.019

Kayser[b] attempted to express in absolute units the dependence of the absorption by glass fiber upon temperature and pressure. His aim was to measure the quantity of gas condensed by a known surface under definite temperature and pressure (and therefore with known concentration of the vapor phase) and to utilize this relation to estimate the surface of fine powders from the quantity of gas they absorb. But he was forced to abandon this, since adsorption is not dependent solely upon extent of surface, temperature, and pressure. He found (1) that glass fiber dried for a long time at high temperature adsorbs carbon dioxide, a few hours being required for saturation; (2) the adsorption increases with the pressure, and (3) decreases as the temperature increases.

A little later Bunsen,[c] using similar materials (glass fiber and carbon dioxide), obtained results at variance with those of Kayser, as follows: (1) Glass is not saturated with carbon dioxide in days or months, but only after several years have elapsed. Thus 1 sq. cm. of glass adsorbed of carbon dioxide at the end of the first year, 3.15 c. c.; second year, 1.10 c. c. more; third year, 0.88 c. c. more. (2) Sudden pressure and temperature changes never produced a noticeable evaporation of adsorbed carbon dioxide. (3) Sudden change of pressure within one atmosphere showed no effect upon the steady course of adsorption. (4) Within a temperature interval of 0.8° to 23° C., rise in temperature favored adsorption and conversely.

Bunsen[d] then showed that the difference between his results and those of Kayser lay in the method used to dry the glass fiber. At ordinary temperature glass may retain even in very dry air (over P_2O_5) a layer of water as thick at 10.55×10^{-6} mm., and at 107° C. up to 7.03×10^{-6} mm.

Thus it is easy to understand why pressure changes within one atmosphere show little or no effect upon the rate of formation of these thin films where the pressure amounts to hundreds of atmospheres. Likewise the solution of gases in these thin films under high pressure appears reasonable, as well as the long period of time necessary for the establishment of equilibrium.

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[a] Forsch. Geb. Agr.-Phys., **15**, 201 (1892).

[b] Ann. Phys. Chem., **14**, 450 (1881).

[c] Ann. Phys. Chem., **20**, 545 (1883); **22**, 145 (1884).

[d] Ann. Phys. Chem., **24**, 321 (1885).

Mülfarth[a] has investigated the adsorption of gases by glass powders, with the following results: (1) Perfectly dry glass powder adsorbs a considerable mass of carbon dioxide. This is contrary to the experimental results of Krause.[b] (2) Glass powder dried at 420° C. and rendered free from gas shows an adsorption of carbon dioxide as great as glass dried at 500°. (3) The adsorption of the CO_2 by completely dried glass powder is normal; that is to say, it increases with increasing pressure and decreases with increasing temperature. (4) The adsorption of carbon dioxide by dried glass powder is completed in a short time—from one to two hours. (5) The presence of moisture renders the adsorption of CO_2 slower; nevertheless, in a few days it proceeds to completion, and the mass adsorbed is not greatly different from that taken up by dried glass powder at the same pressure and temperature. Consequently, the main influence of dampness appears to consist in rendering the process of adsorption slower. (6) The quantity of carbon dioxide adsorbed is not nearly so great as Bunsen found in his research using glass fiber. (7) The adsorption of sulphur dioxide by dried glass powder proceeds exactly like that of carbon dioxide, is completed in two hours, increases with increasing pressure, and decreases with increasing temperature. (8) At zero degress the following gases are adsorbed by glass powder and in the following order: Ammonia, sulphur dioxide, carbon dioxide, nitrous oxide (N_2O), acetylene, in descending series. The gases, sulphur dioxide and ammonia, which are most easily condensed to liquid, are the most strongly adsorbed. Nitrous oxide and carbon dioxide, which stand very near to each other in respect to the ease of their condensation at low pressures, are almost equally well adsorbed, but carbon dioxide a little more strongly. (9) Henry's law holds fairly well also for the adsorption of gas on glass powder.

Absorption of ammonia.

Ammon[c] found that ammonia is absorbed by soil constituents as follows: Humus at 20° C., 11.5 per cent of its dry weight; ferric hydroxide, 4.7; quartz powder, 0.295; calcium carbonate, 0.23; kaolin, 0.42. When pure ammonia gas is absorbed, small quantities of nitric acid are formed, relatively more in ferric hydroxide than in the other soil constituents. The absorption of ammonia in general decreases with increase in temperature, but near zero, Centigrade, the maximum quantity of gas is taken up, less being absorbed at lower as well as at higher temperatures. In view of the more recent work by Dewar[d] and others on the absorption of gases at low temperatures the actual existence of such a maximum as Ammon found is open to question.

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[a] Ann. Phys. (4), 3, 328 (1900).

[b] Ann. Phys. Chem., 36, 923 (1889).

[c] Forsch. Agr.-Phys., 2, 34 (1879).

[d] Chem. News, 94, 174 (1906).

Von Dobeneck[a] has confirmed Ammon's conclusion that the absorption of ammonia is less the higher the temperature when working above zero, Centigrade. Von Dobeneck's quantitative measurements on the absorption of ammonia are in general of the same order of magnitude as those given by Ammon, and in addition von Dobeneck has shown that mixtures of soil constituents absorb ammonia and other gases additively, each material exerting its absorption effect independently of the others. He showed, too, that where a moist powder absorbs ammonia, the quantity of gas retained is very considerably in excess of what the water can dissolve when separate from the powder. Thus, 100 grams water dissolved 43.9 grams of ammonia, but when this same mass of water was held by 854 grams of kaolin, 56.5 grams of ammonia were absorbed, an increase of 28.6 per cent; with 472 grams kaolin and 100 grams water, 55.7 grams ammonia were absorbed. Similarly the following powdered solids, each wet with 100 grams water absorbed ammonia: 445 grams calcium carbonate, 54.6 grams; 435 grams quartz, 53.1 grams; 329 grams kaolin, 54.0 grams; 200 grams ferric hydroxide, 47.2 grams; 202 grams humus, 78.5 grams; 186 grams kaolin, 51.9 grams.

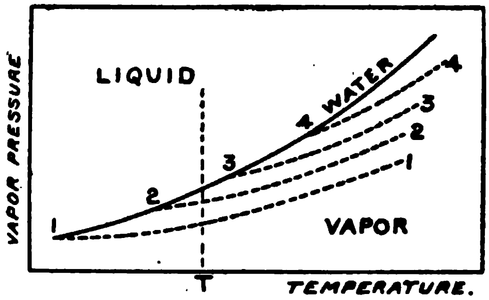

FIG. 9.- Curves showing vapor pressure of water, and of moist soils at various temperatures for case I, assuming that absorption increases with rise in temperature.

Schlösing[b] found that soils, whether acid or alkaline, dry or wet, absorbed ammonia from the atmosphere in appreciable amount. Calcium carbonate in the soil increases the absorption capacity of the soil for ammonia. Absorption is in a high degree dependent upon a continual renewal of air at the surface of the soil, consequently, it makes a difference whether the surface be bare or covered with vegetation, since the plants tend to prevent circulation of the air in a layer near the surface.

Pfeiffer[c] showed that equal changes in pressure produce about equal changes in the quantity of gas absorbed by different sorts of carbon. He found that the absorption of ammonia by charcoal decreased about one-half on heating from 0° to 70° C.

Absorption of hydrogen.

The absorption of hydrogen is of minor importance from the standpoint of soil chemistry. Joulin[d] showed that ignited charcoal absorbs hydrogen so rapidly as to render difficult a measurement of the velocity, and recently Travers[a] has studied the absorption of hydrogen by cocoanut charcoal at different temperatures. The numerous investigations on the absorption of hydrogen by metals need only be mentioned in this connection.[b]

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[a] Forsch. Agr.-Phys., **15**, 201 (1892).

[b] Compt. rend., **110**, 429, 99 (1890).

[c] Über die Verdichtung von Gasen durch feste Körper; Inaug. Diss. Erlangen (1882).

[d] Compt. rend., **90**, 741 (1880).

EFFECT OF TEMPERATURE UPON ABSORPTION.

THEORETICAL CONSIDERATIONS.

Assuming for the particular substance, water, that the quantity of moisture absorbed by a soil from a saturated atmosphere varies with the temperature, there are two possible cases:

(1) The amount of water absorbed increases with the rise in temperature. For this case the vapor-pressure-temperature curves for the soils will cut the vapor-pressure-temperature curve for water, as shown in figure 9; this has apparently been realized experimentally by Hilgard.[c]

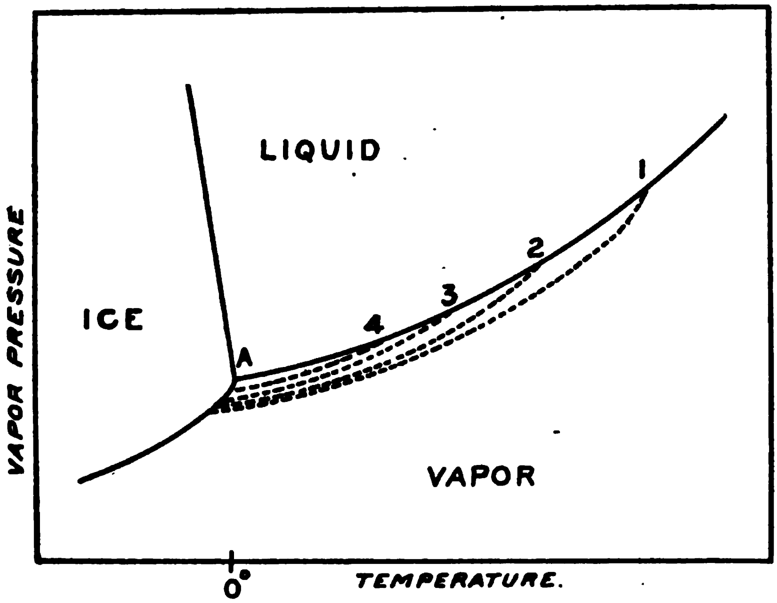

FIG. 10.—Curves showing vapor pressure of water, and of moist soils at various temperatures for case II, assuming that absorption decreases with rise in temperature.

(2) The amount of water absorbed from a saturated atmosphere decreases with rise in temperature. This case is illustrated by figure 10. Here the lower limit of the vapor-pressure curves for soils is the vapor-pressure-temperature curve for ice, and the maximum quantity of water absorbed at any temperature whatever is the mass of water which can remain adsorbed by the soil, in equilibrium with

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[a] Proc. Roy. Soc. London, 78, Ser. A, 9–22 (1906).

[b] See Fischer, Ann. Phys. (4), 20, 503 (1906).

[c] "Soils," pp. 196, 198 (1906).

the complete system—ice, "liquid water," water vapor, which exists at the triple point A. The dotted curves in figure 10 show the vapor-pressure-temperature curves for soils. The quantity of moisture in the soil remains constant along the dotted curve, which is limited in extent; above, it meets the vapor-pressure curve of liquid water; below, it cuts the vapor-pressure curve for ice. Here the absorbed water would begin to freeze at a lower temperature than free water; and when we remember the enormous stress under which water exists when in adsorbed condition, this conclusion is not surprising.

EXPERIMENTAL DATA AND DISCUSSION.

Four series of preliminary experiments were carried out. In the first three series 10-gram samples of dry quartz flour, Podunk fine sandy loam, and Sea Island cotton soil were brought to equilibrium with water vapor in desiccators at various temperatures in the thermostat. The general trend of these results serves very well to show that the mass of water vapor absorbed decreases with the temperature. And by comparison of this series for Sea Island cotton with a later series for the same soil under rigid conditions, using stoppered weighing bottles to avoid loss of moisture on the balance, the exact experimental error is seen at each point.

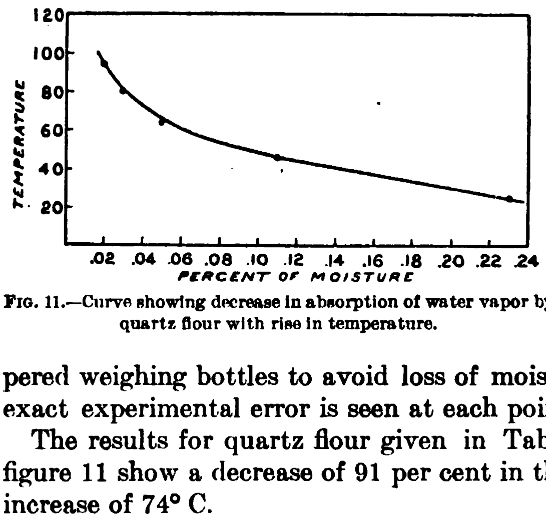

FIG. 11.—Curve showing decrease in absorption of water vapor by quartz flour with rise in temperature.

The results for quartz flour given in Table XIII and plotted in figure 11 show a decrease of 91 per cent in the water absorbed for an increase of 74° C.

TABLE XIII.—*Decrease of absorption with temperature rise for quartz flour*[a] *in open dish over water.*

Temperature.	Water held by soil.
°*C.*	*Per cent.*
23	0.23
43	.11
62	.05
80	.03
97	.02

[a] The same sample was used throughout.

Table XIV.—*Decrease of absorption with temperature rise for Podunk soil in open dish over water.*

Temperature.	Water held by soil.
°C.	*Per cent.*
25	0.81
43	.35
62	.16
80	.11

Table XV.—*Decrease of absorption with temperature rise for Sea Island cotton soil in open dish over water.*

Temperature.	Water held by soil.
°C.	*Per cent.*
25	8.4
62	4.84
80	3.84

Table XVI.—*Decrease of absorption with temperature rise for Sea Island cotton soil in weighing bottles over water.*

Temperature.	Water held by soil.
°C.	*Per cent.*
25	9.7
100	5.5 5.4

Podunk fine sandy loam confirms the general trend shown by quartz, as seen in Table XIV and figure 12. The soil absorbs over 50 per cent less water vapor at 43° than at 25°, and a rise in temperature of only 55°, from 25° to 80°, reduces the moisture content at equilibrium by 86 per cent. Sea Island soil in open dishes over water shows in Table XV a decrease in absorption of 42 per cent for a rise of 32°, and of 54.2 per cent for 55°.

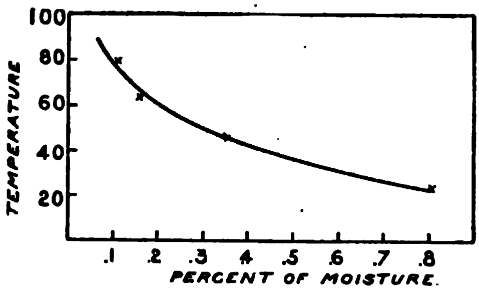

Fig. 12.—Curve showing decrease in absorption of water vapor by Podunk soil with rise in temperature.

A fourth series for Sea Island cotton soil is given in Table XVI. The quantity of water absorbed at 25° over water in a desiccator was determined, using a 20-gram sample in a weighing bottle which could be closed during the weighing to avoid evaporation. The data for this point are taken from the lower half of Table IV and were obtained under accurately controlled temperature conditions; the equilibrium conditions were established after a run of ninety-seven days.

The absorption at 100° C. was found by inclosing the weighing bottle with its 20-gram soil sample in a sealed tube over water. This tube was immersed in boiling water, as shown in figure 13, where T is the sealed tube; W, the weighing bottle; S, a copper support to hold the bottle out of the water; G, a safety guard of gauze surrounding the tube T and also serving as a support; C, a cork support for T and G; H, hooks holding the gauze G to the cork C; B_1, a beaker containing boiling water nearly to the level of the cork C; B_2, a tall beaker inverted over B_1 and serving as a condenser.

With this arrangement water need be added to B_1 only every two days. On account of the high temperature, absorption proceeded rapidly to completion; equilibrium was established within a week, as shown by the values given in Table XVI. After one week 5.5 per cent of moisture had been absorbed, and another week's run gave practically the same value, 5.4 per cent; so the system had come to equilibrium. The difficulty met with in the other experiments, Tables XIII, XIV, and XV, did not enter here, since a closed weighing bottle was used.

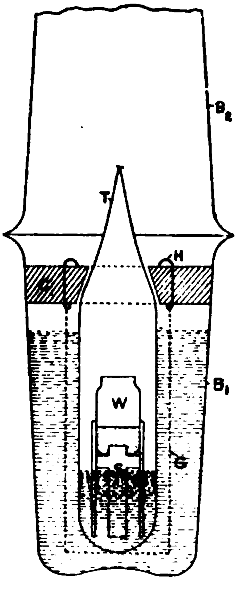

FIG. 13.—Diagram of apparatus used to determine absorption of water vapor by soil at the boiling point of water.

The data for the two points in Table XVI are shown in figure 14 as curve 1, and for comparison the data from Table XV are given on the same plot and to the same scale, with temperature as ordinate and percentage moisture in the soil as abscissa. It is evident that the determinations made in open dishes, curve 2, show less moisture than those made in weighing bottles, curve 1. At 80° C. this loss of absorbed moisture from an open evaporating dish during weighing amounts to nearly 40 per cent, at 25° C. this loss is 13 per cent, and for 100° C. extrapolation of curve 2 indicates a loss of some 48 per cent of the total. The curves in figs. 11,

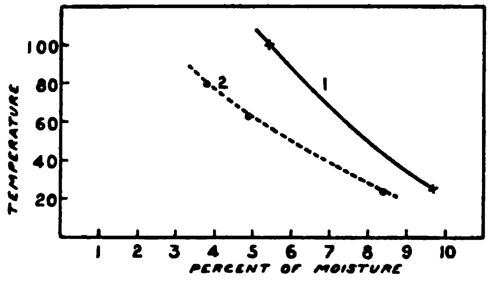

FIG. 14.—Curve showing decrease of absorption of water vapor by Sea Island cotton soil with rise of temperature.

12, and 14 show the same general trend, and together with the most accurately determined points in Table XVI and curve 1, figure 14, show a decrease of absorption as temperature rises in a manner not open to question. All of these curves bend upward steeply at higher temperatures, since the absorbed moisture is held more firmly the thinner the layer in which it is spread upon the soil grains.

Thus it is proved experimentally that absorption of water vapor by soils decreases very greatly with rise in temperature. A departure from equilibrium conditions, which indeed seldom obtain in the field, shows even greater decrease in the quantity of absorbed water as the temperature increases.

ABSORPTION CAPACITY.

It is of interest to see how the absorption data are related to the surface presented by the grains of the different soils used. For this purpose a general survey of the quantity of vapors absorbed by some of the soils studied in the foregoing sections is given in Table XVII.

Unfortunately the area of a soil as calculated from its mechanical analysis (Table XVIII) can give only an approximate result, probably much below the true value. Thus in Table XVII it is seen that Galveston clay absorbs three times the mass of water vapor that Marshall silt loam takes up, while the calculated area of the clay is not three times as great but less than a third greater than the silt loam. The results obtained with toluene were in general similar to those obtained with water. The ether vapor behaves differently, the clay taking in a smaller quantity than would be predicted from the water and toluene results.

Table XIX contains the calculated thickness of the layer of liquid absorbed upon the grains of each soil. The following assumptions were made in deriving these values: (1) That the film of absorbed vapor is uniform in thickness over all the soil grains; (2) density of water, 1; density of toluene, 0.89; density of ether, 0.73; as these densities are probably lower than the density of the surface film the value for the thickness of film is probably too high; (3) density of individual soil grains, 2.5; (4) that the soil grains are spheres; this assumption probably gives a value of the film thickness much too high; (5) that the fractions in the mechanical analyses are clean separations. In the last two fractions the diameters of the grains vary within relatively wide limits. The area of the soil grains is probably several times greater than the value given in Table XVII. For example, the quantity of water absorbed by Galveston clay is much greater than would be expected from its area when the absorption capacity of the other soils and their areas are considered. The clay and silt in the Galveston clay greatly increase its surface beyond that calculable from a mechanical analysis. It was on this account that the soil separate with grains varying only between 0.1 and 0.05 mm. in diameter was used in this series, so that a more accurately determined surface might be used for the determination of its absorption capacity.

TABLE XVII.—*Area of soil grains as related to absorption capacity for vapors.*

Soil.	Area per gram.	Water absorbed.		Ether absorbed.		Toluene absorbed.	
		Eight days.	Maximum.	Eight days.	Maximum.	Eight days.	Maximum.
	Sq. cm.	*Per ct.*	*Per cent.*	*Per ct.*	*Per cent.*	*Per ct.*	*Per cent.*
Galveston clay	3,280	8.00	12.00	4.80	6.00	4.79	....
Marshall silt loam	2,320	2.84	4.00	2.86	4.00	1.62	1.7
Hagerstown loam	2,270	2.90	4.50	3.30	4.50	1.85	....
Quartz flour	1,260	.35	.80	....	....	.29	.4
Soil separate (0.1–0.05)	320	.67	1.00	.77	.77	.41	....
Norfolk sand	300	.29	.45	.45	.62	.17	....

TABLE XVIII.—*Mechanical analyses.*

Soil.	Average diameter of grain.						
	2–1 mm.	1–0.5 mm.	0.5–0.25 mm.	0.25–0.1 mm.	0.1–0.05 mm.	0.05–0.005 mm.	0.005–0 mm.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Galveston clay	0.7	1.5	0.40	7.0	28.9	30.1	31.00
Hagerstown loam	.9	3.0	2.10	6.5	13.9	54.3	19.10
Marshall silt loam	1.3	2.8	1.70	4.3	12.9	56.9	19.50
Quartz flour	.0	.0	.05	.2	8.0	86.2	5.42
Norfolk sand	.2	6.3	22.20	63.7	4.1	1.0	1.80

TABLE XIX.—*Comparison of absorption capacity of soils for vapors.*

Soil.	Vapor.	Total quantity absorbed.	Quantity per sq. cm. × 10⁵.	Thickness of layer.	Energy = latent heat × grams absorbed.
		Grams.	*Grams.*	*Cm. × 10⁵.*	
Soil separate (0.1–0.05). 8 days absorption.	Water	0.6417	2.00	2.00	378.2
	Toluene	.4049	1.26	1.42	33.8
	Ether	.770	2.40	3.25	65.8
Galveston clay, maximum absorption	Water	12.00	3.66	3.66	7,080.0
	Toluene	6.00	1.83	2.06	501.0
	Ether	6.00	1.83	2.51	518.0
Marshall silt loam	Water	4.00	1.72	1.72	2,360.0
	Toluene	1.70	.73	.82	240.0
	Ether	4.00	1.72	2.35	345.0
Hagerstown loam	Water	4.50	1.98	1.98	2,655 0
	Toluene	1.85	.82	.92	155.0
	Ether	4.00	1.68	2.31	345.0
Norfolk sand	Water	.45	1.50	1.50	265.5
	Toluene	.25	.83	.94	20.9
	Ether	.62	2.06	2.83	53 5
Quartz flour	Water	.80	.64	.64	471.0
	Toluene	.40	.32	.36	334.0

TABLE XIX.—*Comparison of absorption capacity of soils for vapors*—Continued.

Soil.	Vapor.	Vapor pressure.	Temperature.	Surface tension.	Viscosity.	Density.
		Mm.	°*C.*	*C. G. S.*	*C. G. S.*	*C. G. S.*
Soil separate (0.1–0.05). 8 days absorption.	Water	28.1	28	73	0.01	1.00
	Toluene	33.5	28	28	.0056	.89
	Ether	575.0	28	17	.0024	.73
Galveston clay, maximum absorption.	Water	28.1				
	Toluene	33.5				
	Ether	575.0				
Marshall silt loam	Water	28.1				
	Toluene	33.5				
	Ether	575.0				
Hagerstown loam	Water	28.1				
	Toluene	33.5				
	Ether	575.0				
Norfolk sand	Water	28.1				
	Toluene	33.5				
	Ether	575.0				
Quartz flour	Water	28.1				
	Toluene	33.5				

This soil separate shows a film 2.0×10^{-5} cm. thick, as against a thickness of 3.66×10^{-5} cm. for Galveston clay and 1.5×10^{-5} for Norfolk sand, while Hagerstown loam and Marshall silt loam give values nearer that of the soil separate. Parks[a] gives a value for the thickness of a water film absorbed on glass wool, 1.34×10^{-5} cm., which agrees closely with these results.

In general, toluene gives a thinner film than water, while the ether layer is thicker than that of water for all soils save Galveston clay.

If we assume the average diameter of a clay particle as 0.0002 cm., and consider it to be a sphere, its volume is 4.19×10^{-12} c. c. If the water film be uniform in thickness over the surface of all the grains, 2.00×10^{-5} cm., as given for the soil separate, then the total volume of this clay particle with its absorbed water will be 7.25×10^{-12} c. c., and the volume of water alone 3.06×10^{-12} c. c., or 73 per cent of the volume of the clay particle holding it, and the radius of the particle is only ten times greater than the thickness of the water layer surrounding it. There is very little doubt that this hygroscopic water is in part held in the fine capillary spaces between the soil grains,[b] but we have no sharp experimental method of ascertaining what fraction of the water is thus retained.

A comparison of the quantities of water, toluene, and ether absorbed by the various soils, with their surface tensions, viscosities, vapor pressures, and latent heats of evaporation does not give a clue to the different absorption capacities found. It seems that each vapor has its own specific action which finds a counterpart in the selective absorption exercised by the soil. For any one vapor the absorption capacity of a soil is roughly proportional to the soil grain surface as calculated from the mechanical analysis.

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[a] Loc. cit.

[b] Katao, Über die Wasserbewegung in Boden, Bul. Col. Agr., Imp. Univ., Tokyo, Vol. 3, No. 1, 1897; Soyaka, Forsch. Agr. Phys. 8, 1 (1885); Whitney, Agricultural Science, Vol. 3, p. 199, 1889; Briggs, Bul. No. 10, U. S. Dept. of Agriculture, Division of Soils (1897).

Finally, we see from the above considerations that for any one vapor the amount of absorption is proportional to the calculated soil area exposed, and that the thickness of film on any given soil surface varies with the nature of the vapor, but the data at present available are not sufficient to show that the thickness of the film is dependent upon the nature of the soil type.

DISTRIBUTION.

Solids in general do not completely absorb gases or vapors, but rather the gas is divided between the atmosphere and the solid. The greater the quantity of gas or vapor in the atmosphere, the more of it is held fixed by the solid, until the solid becomes saturated and can retain no more of the gas. A number of attempts have been made to express this relation between the quantity absorbed by the solid and the concentration of gas in the atmosphere, as a fairly simple mathematical equation. The chemical composition of the solid and that of the gas of course determine in great measure the degree to which absorption takes place, and this factor is expressed by a constant which is different for each solid and gas studied. The effect of temperature upon absorption is likewise recognized in the formula by a constant whose value changes with the temperature.

De Saussure[a] has suggested the formula $V = 19.1 + 0.53\ P$, where V is the volume of gas adsorbed and P is the pressure in inches of mercury. This relation holds for carbon dioxide.

Ostwald[b] applies to gaseous adsorption the equation, $\frac{x}{m} = \alpha C^{\frac{1}{p}}$, which was developed for adsorption from solution, where x is the mass of gas adsorbed; m the mass of adsorbent solid; C the concentration of the vapor phase; α is a constant; and $\frac{1}{p}$ is an exponent. Freundlich holds that adsorption from solution and from vapor by solids follow the same law, and Ostwald's exponent, $\frac{1}{p}$ equals $1 - \frac{1}{n}$, where $\frac{1}{n}$ is the exponent in the equation,[c] $\lambda = \alpha\left(\frac{a}{v}\right)^{-\frac{1}{n}}$, proposed by himself.

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[a] Loc. cit.

[b] Lehrbuch der Allgemeine Chemie, II (2 Aufl.) 232.

[c] $\lambda = \alpha\left(\frac{a}{v}\right)^{-\frac{1}{n}}$ is simply an empirical relation, and is not derived analytically from the other equation, $\lambda = \frac{v}{m} \ln\left(\frac{a}{a-x}\right)$ given by Freundlich. λ and α are constants; a is total mass of gas in the system, and v is the volume of space available for the gas.

Thus Freundlich found working with liquid solutions, values for $\frac{1}{n}$, which range from 0.86 to 0.485, giving to $\frac{1}{p}\left(=1-\frac{1}{n}\right)$ values from 0.14 to 0.515. But the $\frac{1}{p}$ given by Ostwald on the basis of Chappuis,[a] Joulin,[b] and Kayser's[c] results, for CO_2 adsorbed by various kinds of charcoal, is higher, varying from 0.50 to 0.75. Further, Chappuis's curve for $\log \frac{x}{m}$ against C is very concave for carbon dioxide, whereas if the exponential formula $\frac{x}{m}=\alpha C^{\frac{1}{p}}$ applies, this curve should be a straight line. So this formula of Ostwald's holds only indifferently well as far as this gas is concerned.

Recently Travers[d] has determined the distribution of hydrogen and of carbon dioxide between cocoanut charcoal and the vapor at 100°, 60°, 35°, 0° and $-78°$, and for hydrogen at $-190°$ C. He suggests the formula, $\sqrt[n]{\frac{P}{x}}=a$ constant, where P is the gas pressure and x the concentration of the gas, in the solid phase for each temperature. The value of n increases when the temperature falls. For CO_2 at 0°, $n=3$; at 100°, $n=2$; at higher temperatures n would probably equal 1 and then the distribution law would hold exactly—i. e., become linear—but it is possible, too, that n might fall below 1. Hydrogen at $-190°$ behaves exactly like CO_2 at 0°; that is, $n=3$. Travers attributes the departure of the distribution law from a linear form at low temperatures to the influence of diffusion into the solid phase. On the contrary, Trouton[e] has assumed the formation of a liquid phase upon the surface of the solid to explain his curves representing the absorption of water vapor by cotton.

It is seen that no one mathematical expression yet proposed describes the present data for the adsorption of gases by solids. The specific attractions of solid and gas, the diffusion of gas into solid, the condensation of gas to liquid, and the consequent clogging of capillary channels where the forms and arrangement of these minute spaces enter to determine the vapor pressure of the liquid there enmeshed, all these factors complicate the observed relation of mass of gas adsorbed to mass of gas left in the vapor phase.

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[a] Ann. Phys. Chem., **12**, 161 (1881).

[b] Ann. Chim. Phys. (5), **22**, 397 (1881).

[c] Ann. Phys. Chem., **12**, 526 (1881).

[d] Proc. Roy. Soc. London, **78**, Ser. A, 9 (1906).

[e] Proc. Roy. Soc. London, **77**, Ser. A, 292 (1906).

RATE OF ABSORPTION.

DETERMINING FACTORS.

The rate at which a solid absorbs a vapor depends upon several factors. These will be discussed in the following paragraphs.

Chemical composition.

In general, the chemical composition of the solid affects absorption to the extent that acid bodies tend to absorb basic vapors, and conversely. The magnitude of this influence varies from very pronounced chemical reaction, such as the fixation of gaseous ammonia by solid acids to extremely weak acid or basic effects.

Physical condition.

The physical condition of the solid, its fineness of division, determines the surface available for the purely adsorption effect, which, with other conditions the same, is directly proportioned to the surface of the solid in contact with the vapor. As the solid is reduced to finer powder the number of solid angles between the granules is increased, as well as the surface of solid exposed, and the condensed vapor retained in these solid angles is added to that held by simple absorption.

Viscosity of the vapor.

In the case of vapor entering a soil at rest there is a damping term due to the viscosity of the vapor. After taking account of the probable diameter of the capillary spaces through which the vapor is to pass, the resistance which the vapor offers to being forced into the soil is the viscosity of the vapor multiplied by its rate of flow,[a] and this rate of flow is the rate at which absorption is taking place. The diameters of the capillary spaces, too, become less as the surface of each grain takes on moisture, so the resistance to the passage of vapor increases as the absorption proceeds. Consequently we should expect rate curves for soils to show a decrease in rate of absorption with time greater than that for absorption of vapor upon a plane surface, but this factor has been found to be of only minor import.

Absorption capacity.

The absorption capacity of the solid affects the rate of absorption to a marked degree. Where the absorption capacity is high, the speed of absorption is very great.

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[a] See E. Wollny, Forsch. Agr.-Phys. 16, 193 (1893); Buckingham, Bul. No. 25, Bureau of Soils, U. S. Dept. Agr. (1904).

Partial pressure, or humidity.

The rate of absorption of water by soils varies for atmospheres of different humidity in a manner similar to the change in rate of evaporation under different degrees of humidity, as can be seen from the curves in figure 15 for Sea Island cotton soil plotted from the data given in the lower half of Table IV. Ordinates are in percentage of moisture in the soil, abscissas are in time in days. All the experiments begin at 4.4 per cent of moisture, the quantity retained by Sea Island cotton soil in air-dry condition.

Van Bemmelen,[a] Hellriegel,[b] Puchner,[c] and von Dobeneck[d] have determined the speed with which a soil absorbs water vapor.

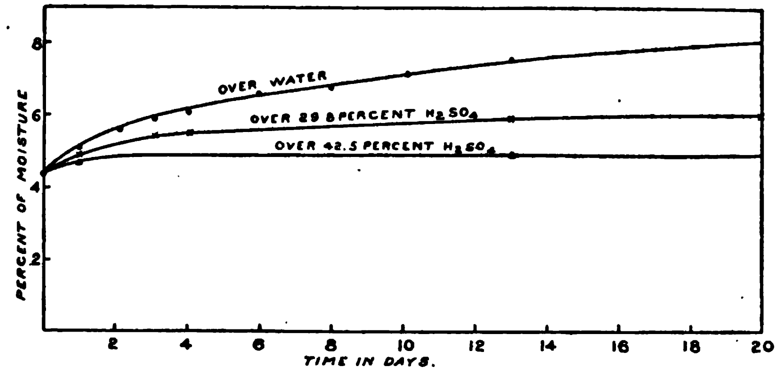

FIG. 15.—Curves showing rate of absorption of water vapor by Sea Island cotton soil under different degrees of humidity.

They, too, give very regular rate curves, but these, as well as Parks[e] rate of absorption of water vapor by glass wool, are likewise not described by a simple mathematical formula. Hantzsch[f] has shown that the rate of absorption of ammonia gas by solid organic acids in finely powdered condition depends upon the partial pressure of the ammonia gas in the atmosphere above the solid acid. Using absolute ammonia, the reaction is fairly well described by the first order reaction velocity equation, $K^{I.} = \frac{1}{t} \log.\left(\frac{a}{a-x}\right)$, and on dilution of the ammonia with air, this equation still holds if the total volume of gas employed is so great that the partial pressure of the ammonia is practically constant throughout the absorption process.

If, however, the quantity of ammonia present in the gas is considerably reduced by the absorption, then the rate of absorption is no longer expressed by this first order reaction velocity equation, but is more nearly given by the second order equation, $K^{II.} = \frac{1}{t} \frac{x}{(a-x)a}$. The same is true for the absorption of gaseous hydrogen chloride by solid organic bases. A similar effect is produced in the rate of absorption of water vapor by a soil as the atmospheric humidity varies.

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[a] Arch. Néer. (2), **10**, 267 (1906).

[b] Forsch. Agr.-Phys. **6**, 389 (1883).

[c] Land. Vers.-Stat., **46**, 229 (1895).

[d] Forsch. Agr.-Phys., **15**, 163 (1892).

[e] Phil. Mag. (6), **5**, 518 (1903).

[f] Zeit. phys. Chem., **48**, 289 (1904).

The rates of absorption of water vapor by humus from atmospheres saturated at different temperatures, as determined by von Dobeneck (Table XX), show, too, that the velocity of absorption is greater the higher the relative humidity.

The rate curves obtained from all of the foregoing tables are regular, but are not described by a simple velocity equation.

TABLE XX.—*Rate of absorption of water vapor by humus, according to von Dobeneck.*

Period.	Quantity of water absorbed at—						
	[a] 0° C.	[a] 10° C.	[a] 20° C.	[a] 30° C.	[b] 10° C.	[b] 20° C.	[b] 30° C.
Days.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	0.12	1.40	1.96	3.59	1.35	1.61	2.14
2	.50	2.47	3.22	6.27	2.22	2.48	2.29
3	.88	3.61	4.84	8.13	3.24	2.99	2.32
4	1.25	4.57	5.77	10.03	4.37	3.47	2.36
5	1.79	5.44	7.11	11.17	5.28	3.63	2.39
6	2.28	6.19	8.33	12.39	6.17	3.77	2.43
7	2.79	7.01	9.36	13.61	6.76	3.92	2.42
8	3.30	8.11	10.18	14.20	7.28	4.01	2.45
9	3.76	8.76	10.88	14.65	7.61	4.08	2.49
10	4.23	9.34	11.39	15.34	7.91	4.13	2.48
12	5.06	9.65	12.51	15.98	8.32	4.15	....
14	5.95	10.37	13.32	....	8.49	....	....
16	6.89	11.13	14.03	....	8.60	....	....
18	7.60	12.02	14.64	....	8.63	....	....
20	8.32	12.83	15.02	....	....	....	....
22	9.09	13.62	15.28	....	....	....	....
24	9.90	14.20	15.56	....	....	....	....
26	10.61	14.70	15.86	....	....	....	....
28	11.22	15.03	15.89	....	....	....	....
30	11.83	15.38	....	....	....	....	....
32	12.43	15.68	....	....	....	....	....
34	12.96	15.95	....	....	....	....	....
36	13.48	....	....	....	....	....	....
38	13.99	....	....	....	....	....	....
40	14.46	....	....	....	....	....	....
42	14.89	....	....	....	....	....	....
44	15.25	....	....	....	....	....	....
46	15.59	....	....	....	....	....	....
48	15.79	....	....	....	....	....	....
50	15.90	....	....	....	....	....	....

[a] Atmosphere saturated with moisture at temperature given.
[b] Atmosphere saturated with moisture at 0°.

Previously absorbed vapor.

As will be seen from the data on the rate of absorption of vapors by soils in Tables II, III, IV, V, VI, VIII, IX, X, and XI, the rate of absorption decreases as more and more vapor is held by the soil. This effect is only what would be expected when we remember that the last portions of vapor absorbed and condensed to liquid form exist to a considerable extent in the capillary spaces of the soil as well as in the form of films upon the surface of the soil grains.

Temperature.

(*a*) It has been shown by the investigations cited above and by the new experiments given in the section on the effect of temperature upon absorption, that in saturated atmospheres, at least, an increase in temperature decreases the mass of vapor absorbed by a solid. (*b*) Increase in temperature increases the mass of vapor which a given volume of air can hold at any one pressure. Theoretically, then, the first temperature effect (*a*) should reduce the time required to saturate the absorbing solid with vapor; and the second effect (*b*) should likewise hasten the absorption by providing a higher absolute quantity of vapor in the atmosphere for the solid to draw upon. This conclusion is borne out experimentally by the results obtained with Sea Island cotton soil; at 100° C. only one week was required for this soil to absorb all the vapor it could take up, whereas at 25° C. this same soil stood ninety-seven days over water before it ceased to absorb moisture. Von Dobeneck[a] confirms this effect of temperature upon rate of absorption as shown in Tables VII and XX.

Joulin[b] found that the time required to saturate charcoal with carbon dioxide decreased with increasing temperature at a constant pressure.

RATE OF EVAPORATION.

In a former bulletin the mechanism of evaporation has been discussed in considerable detail.[c] In addition to the data on the evaporation of moisture from soils under various degrees of humidity, which have been given in Tables II, III, and IV, above, we repeat here in Tables XXI, XXII, XXIII, and XXIV the data in that bulletin on the rate of evaporation from wet soils over concentrated sulphuric acid at 25° C. The point brought out by the evaporation data in all of these tables is that the rate of evaporation from any wet soil is fairly constant until the quantity of moisture still remaining in the soil is approximately that known as the "optimum water content" of the soil. At this point a gradual change in the rate of evaporation takes place, as shown in figures 16, 17, 18, and 19, which represent graphically the rate of evaporation indicated in Tables XXI, XXII, XXIII, and XXIV. Referring back to figures 1, 2,

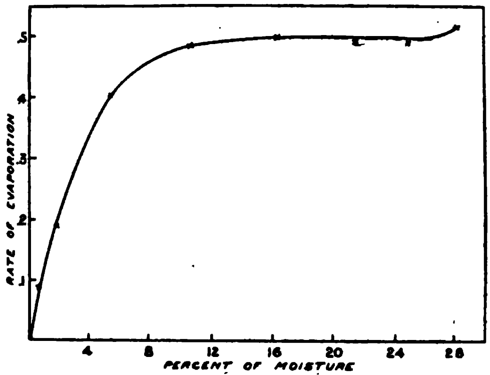

FIG. 16. Curve showing rate of evaporation of water from Podunk soil.

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[a] Loc. cit.

[b] Comp. rend., 90, 741 (1880).

[c] Cameron and Gallagher, Bul. 50, Bureau of Soils, U. S. Dept. Agr., 1907.

and 3 we see this same bend in the rate of evaporation curves, which becomes less and less evident as the humidity of the atmosphere of the soil approaches the saturation point, going from the partial pressure of water vapor of 94 per cent sulphuric acid up to that of the vapor pressure of water alone. As was stated in Bulletin 50, the moisture content of each of these soils at which this bend in the rate of evaporation takes place is in reality very close to the content of water in the soil which gives it the best physical condition for plant growth. The reason for this agreement between the point at which the rate of evaporation changes and the point known as the "optimum water content" has been also pointed out in Bulletin 50. The larger open spaces between the soil grains naturally lose their water first, and the later portions of water evaporate more and more from the finer capillary spaces in the soil. When the water content of the soil is reduced to such a degree that the loosely held water in these more open spaces must draw upon the water held as a capillary film upon the soil grains, then very naturally evaporation proceeds more slowly, since the films are held by the soil grains quite tenaciously. At this same moisture content, too, where the pull of the capillary films of water upon the soil grains is brought into evidence, we would naturally expect that the very fine soil particles might be rearranged into larger aggregates and thus furnish a more open structure better suited for access of atmospheric gases and for the penetration of roots.

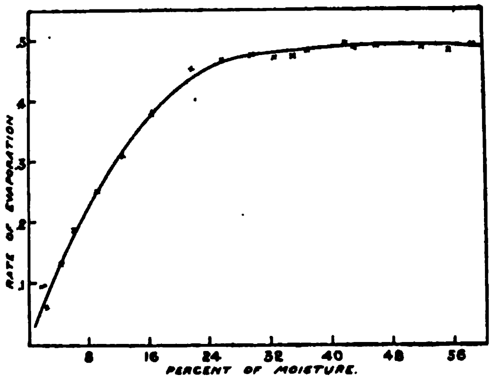

FIG. 17.—Curve showing rate of evaporation of water from Miami soil.

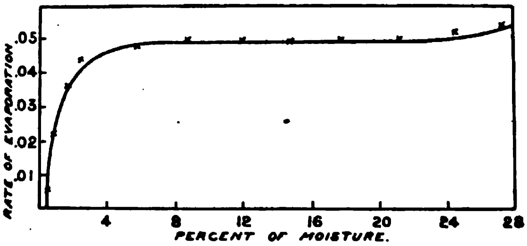

FIG. 18.—Curve showing rate of evaporation of water from Leonardtown soil.

In this connection it is interesting to note that Heinrich[a] has shown that the quantity of water in a soil required for plant growth is always greater than the quantity of water the soil can take up from a saturated atmosphere. A heavy soil containing a high percentage of moisture may hold the water so absorbed that while the plant can get some water, still it is by no means fully supplied.

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[a] Zweiter Ber. landw. Vers.-Stat. Rostock, p. 19 (1894): E. S. R., 7, 481 (1895-96). See also Spalding, Bot. Gaz. 38, 122 (1904).

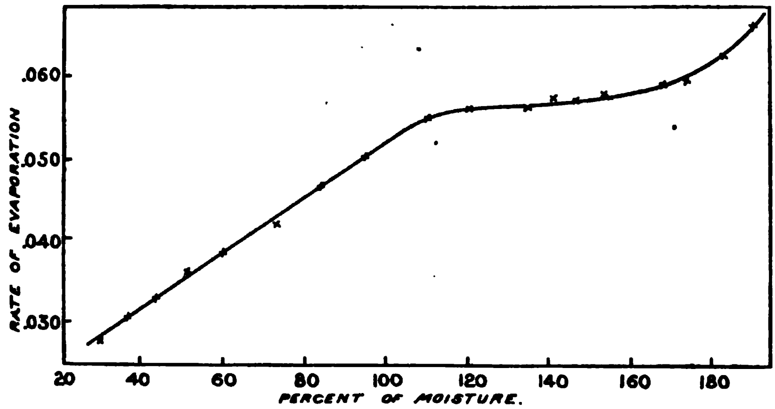

FIG. 19.—Curve showing rate of evaporation of water from muck soil.

TABLE XXI.—*Rate of evaporation from Podunk fine sandy loam over 95 per cent sulphuric acid at 25° C., according to Cameron and Gallagher.*

Mean moisture content.	Period.	Loss of moisture.	Loss per hour.
Per cent.	*Hours.*	*Grams.*	*Grams.*
27.4	19.5	1.0450	0.0563
24.2	4.5	.2362	.0525
21.3	18.7	.9210	.0493
17.8	9.3	.4595	.0494
14.8	15.3	.7495	.0490
12.0	9.9	.4854	.0490
8.7	14.5	.7140	.0492
5.8	9.9	.4712	.0476
2.4	4.0	.1732	.0433
1.7	2.0	.0719	.0359
0.9	11.0	.2445	.0222
0.3	2.0	.0097	.0049

TABLE XXII.—*Rate of evaporation from Miami black loam over 95 per cent sulphuric acid at 25° C., according to Cameron and Gallagher.*

Mean moisture content.	Period.	Loss of moisture.	Loss per hour.
Per cent.	*Hours.*	*Grams.*	*Grams.*
58.5	16.70	0.8198	0.0491
55.4	9.30	.4474	.0481
52.4	15.17	.7422	.0489
49.4	9.90	.4802	.0485
46.4	14.50	.7155	.0493
43.4	9.90	.4808	.0486
41.0	11.00	.5427	.0492
37.5	11.00	.5411	.0483
35.4	6.50	.3099	.0477
32.6	17.50	.8295	.0474
29.7	7.00	.3321	.0474
26.9	17.00	.7964	.0468
22.1	24.00	1.0879	.0453
17.1	24.00	.9109	.0379
12.9	26.25	.8108	.0309
9.5	22.25	.5716	.0257
6.7	24.50	.4694	.0192
5.1	22.75	.3056	.0134
3.7	23.75	.2136	.0090
2.7	24.25	.1470	.0061

TABLE XXIII.—*Rate of evaporation from Leonardtown loam over 95 per cent sulphuric acid at 25° C., according to Cameron and Gallagher.*

Mean moisture content.	Period.	Loss of moisture.	Loss per hour.
Per cent.	*Hours.*	*Grams.*	*Grams.*
28.2	19.00	0.9770	0.0517
24.9	7.25	.3555	.0490
21.6	19.25	.9538	.0495
16.4	22.00	1.0962	.0498
10.7	24.50	1.1963	.0488
5.5	22.75	.9193	.0404
2.0	24.25	.4560	.0188
.7	24.16	.0904	.0037

TABLE XXIV.—*Rate of evaporation from muck over 95 per cent sulphuric acid, at 25° C., according to Cameron and Gallagher.*

Mean moisture content.	Period.	Loss of moisture.	Loss per hour.
Per cent.	*Hours.*	*Grams.*	*Grams.*
190	9.50	0.6362	0.0669
183	15.20	.9600	.0632
174	9.85	.5905	.0600
168	14.50	.8639	.0596
154	10.00	.5813	.0581
147	13.00	.7474	.0575
141	6.50	.3744	.0576
135	17.50	.9903	.0566
121	17.00	.9591	.0564
110	24.00	1.3233	.0551
95	24.00	1.2120	.0505
84	26.30	1.2332	.0469
74	22.10	.9329	.0423
60	24.30	.9388	.0387
52	23.00	.8352	.0363
44	24.00	.7958	.0331
37	24.00	.7372	.0307
30	24.50	.6851	.0279

ENERGY CHANGES.

Poggendorff attributes the first experimental work on capillarity to Leonardo da Vinci, 1452–1519. A number of investigators[a] worked in the field before it was discovered that capillary phenomena are accompanied by heat effects. De Saussure[b] during 1812 to 1814 found that heat was evolved during the process of absorption.

Pouillet[c] showed the rise in temperature of various powders and porous substances when moistened with a liquid. Unfortunately, he, as well as several investigators following him, neglected to communicate the weight of powder and of liquid used and their specific heats; so we are unable to calculate the quantity of heat set free. He gives merely the rise in temperature produced by adding liquid to the material, using water, oil, alcohol, and ethyl acetate with finely divided metals, metallic oxides, powdered glass, clay, and other substances, including a number of organic solids. Water added to inorganic solids gave a rise of 0.2° to 0.6° C., while with dried organic material the temperature rise sometimes reached 10° C.

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[a] Ann. Phys. (Gilbert's), **47**, 113 (1814).

[b] For a more extended survey of the literature see Trans. Am. Electrochem. Soc., **11**, 387 (1907).

[c] Ann. Chim. Phys., **20**, 141 (1822); Ann. Phys., **78**, 356 (1823).

Ammon[a] cites the observations of Von Babo[b] on the rise in temperature experienced by dry soils when subjected to an atmosphere saturated with water vapor. These experiments are qualitative only, but they show the existence of the heat effect due to moistening a powder; that it is positive, and that the temperature rise is greater with soils containing humus than without.

Stellwagg[c] found a marked increase in the temperature on moistening various soils and soil constituents with water and on subjecting them to humid atmospheres. But he has given no data enabling us to calculate the number of calories liberated during this adsorption; consequently his data have only qualitative value. He concludes: (1) That the rise in temperature which the soil experiences upon addition of water, in general is greater the drier the soil, the finer its grains, and the lower the prevailing temperature. (2) That the rise of soil temperature on addition of water to a perfectly dry soil is very considerable (8.33° C. for a calcareous sand rich in humus, 6.6° C. for ferric hydroxide, 5.57° C. for a loam soil). (3) That when water vapor is adsorbed by soil constituents a temperature rise is observed as follows: Quartz sand, 0.00–0.25 mm. diameter, 0.88°; quartz powder, 1.08°; precipitated calcium carbonate, 1.47°; kaolin, 2.63°; ferric hydroxide, 9.30°; peat, 12.25° C. (4) That the temperature rise due to adsorption of dry carbon dioxide by dry soil constituents is inconsiderable, with the exception of ferric hydroxide, in which case the rise is 6.9° C., while the moist gas is adsorbed with a much greater temperature increase. (5) That dry soil constituents adsorb dry ammonia and experience a considerable temperature rise: Quartz powder, 0.80°; precipitated calcium carbonate, 0.80°; kaolin, 2.05°; ferric hydroxide, 18.05°; peat, 28.3° C. Moist ammonia shows less temperature rise; for ferric hydroxide and for peat it is, respectively, 14.1° and 23.80° C.

This heat evolved when a vapor condenses upon a solid absorbent was very naturally attributed to the latent heat of vaporization which became available on liquefaction. But Favre[d] found the heat liberated by absorption to be greatly in excess of the latent heat of vaporization, for three different gases; consequently, this assumption had to be abandoned. More recently Dewar[e] has shown that hydrogen, whose latent heat of vaporization at its boiling point is 120 gram calories, gives off six times that quantity of heat when absorbed by charcoal at the boiling point of air. Similarly, oxygen gas when absorbed by charcoal liberates twice the heat due to liquefaction.

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[a] Forsch. Agr.-Phys., 2, 21 (1879).

[b] Mülder, Chemie der Ackerkrume, Band 3, p. 366.

[c] Forsch. Agr.-Phys., 5, 211 (1882).

[d] Lehmann, Molecular-Physik. I, p. 85.

[e] Chem. News, 94, 174 (1906); Proc. Roy. Soc., 74, 130 (1904).

The experiments of Parks[a] indicate that the quantity of water absorbed by a powder from water vapor is very nearly the same as the quantity of water held on the surface of the grains when the powder is immersed in liquid water. He has shown that a silica powder saturated with water vapor gives off no measurable heat when brought into contact with liquid water, whereas the dry silica liberates a definite quantity of heat per square centimeter of surface, and this heat evolution decreases in a perfectly regular manner as the silica powder contains more and more absorbed water vapor.

Masson[b] has shown that the heat evolved when cotton absorbs water vapor is for practical purposes directly proportional to the quantity of moisture absorbed and is very nearly the same as the latent heat of vaporization. He finds the absorption by cotton to be much greater than is warranted by its area as compared with similar experiments using glass wool, and suggests as an explanation that the water absorbed penetrates into the cotton fiber as a solid solution. The thermal effect dealt with here is evidently different from that studied by Parks.[c]

When a gas is absorbed by a metal many interesting physical changes in the metal may be effected. Its volume, hardness, elasticity, electrical conductivity, and single potential and rate of solution in various solvent liquids are changed. The absorption of a gas, too, may depend upon its condition; that is to say, the energy it possesses. For example, free hydrogen gas is very slightly absorbed by iron and some other metals, but hydrogen freshly liberated from combination either by electrolysis or by action of metal upon acid is very strongly absorbed by iron. Palladium, on the other hand, absorbs free hydrogen with great avidity.

SUMMARY.

In the absorption of water vapor by quartz flour, a soil separate, and typical soils, the rate of approach to equilibrium between soil and water vapor has been followed at various degrees of humidity, and these equilibrium points determined.

The amount of water absorbed increases with the humidity, but not in a simple mathematical relation.

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[a] Phil. Mag. (6), **5**, 521 (1903).

[b] Proc. Roy. Soc. London, **74**, 249 (1904–5).

[c] Loc. cit.

Toluene and other vapors were compared with water vapor, using the same soils, and show in general an absorption of the same order of magnitude.

The velocity of absorption decreases regularly as absorption proceeds, but it is not described by a simple logarithmic equation.

Relatively small decrease in vapor pressure produces a marked increase in the rate at which the soil dries out. At the moisture content known as "optimum" for plant growth, a rapid decrease in the rate of evaporation takes place, and at this particular moisture content there are likewise changes in other physical characteristics of the soil, such as specific volume, resistance to penetration, etc., which altogether point strongly to a purely physical reason for the existence of a narrow range of water content in a soil at which plants thrive best.[a]

The content of water in a soil at which plants begin to wilt is greater than the quantity of water the soil can take up from a saturated atmosphere. A heavy soil containing a high per cent of moisture may hold the water so absorbed that while the plant can get some water still it is by no means fully supplied.

The absorptive capacity of soil for water vapor is generally higher the finer the texture of the soil and the greater the content of humus. In general, productive soils have a very considerable capacity for water vapor.

Gases are absorbed to a different degree by each solid substance; the different soil components all possess a considerable absorption capacity, and mixtures of these constituents absorb gases additively; that is, each soil material exerts its absorptive effect independently of the rest of the soil about it. Soil constituents moistened with water absorb gases in greater quantity than would the same mass of water alone. Easily condensed gases are in general absorbed more easily.

Heat is evolved during the process of absorption, and this heat is greatly in excess of that given out by the condensation of the vapor to a liquid.

For equilibria between soils and atmosphere saturated with water vapor over a temperature range from 25° C. to 100° C., the amount of water absorbed decreases with increasing temperature. This confirms the results obtained by earlier investigators for the absorption of water vapor as well as for gases in general.

Absorbed gases are held with remarkable tenacity. Glass and minerals retain hygroscopic water up to 500° to 800° C.

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[a] See Cameron and Gallagher. Bul. 50, Bureau of Soils, U. S. Dept. of Agr., 1907.

Bodies which have been heated and then cooled in a vacuum show high absorptive power; consequently, absorption can not be looked upon solely as the solution of a gas in moisture films upon the grains of the solid.

In general, nitrogen is absorbed by soils in greater quantity than oxygen. This is especially interesting, since the absorption of oxygen and nitrogen from air by water gives a higher ratio of oxygen to nitrogen in the solution than the 1:4 relation which exists in air. The similar high absorptive power of aluminum hydroxide, ferric hydroxide, and magnesium carbonate for nitrogen indicates that this preference of soils for nitrogen is a real phenomenon, since these substances have no way of masking their true absorptive power for oxygen by converting it chemically to carbon dioxide, as a soil does, or to other oxides.

The absorption of carbon dioxide by soils is due in great measure to the presence of hydrated oxides, such as ferric oxide, and humus. Kaolin, calcium carbonate, and quartz also absorb carbon dioxide, but in comparatively small amounts.

Soils, whether acid or alkaline, dry or wet, absorb ammonia from the atmosphere in appreciable amount.

No one mathematical expression has been found to hold generally for the distribution of a gas between the vapor phase and absorbing solid. The specific attraction of solid and gas, the diffusion of gas into solid, the condensation of gas to liquids and consequent clogging of capillary channels where the forms and arrangement of these minute spaces enter to determine the vapor pressure of the liquid there enmeshed, all these factors complicate the observed relation of mass of gas adsorbed to mass of gas left in the vapor phase.

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Issued August 8, 1908.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS—BULLETIN No. 52.
MILTON WHITNEY, Chief.

ABSORPTION BY SOILS.

BY

HARRISON E. PATTEN AND WILLIAM H. WAGGAMAN.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1908.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., February 13, 1908.

Sir: I have the honor to transmit herewith the manuscript of a technical paper entitled Absorption by Soils, by Messrs. Harrison E. Patten and William H. Waggaman of this Bureau.

In accordance with your suggestion, the manuscript has been submitted to Assistant Secretary Hays, who concurs with me in recommending it for publication as Bulletin 52 of the Bureau of Soils.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

In the present bulletin Messrs. Patten and Waggaman have brought together the literature covering absorption of dissolved solids from liquid solutions, together with results of some important experimental investigations which have been carried on in this laboratory in continuance of the general work on soil absorption which has been under way for several years. The importance of this subject for practical soil work, for fertilizer manufacture, and for various technical processes has long been known, but it is only within the past few years that its importance has become generally recognized.

The principal object of this work has been to determine how absorption controls the concentration of the soil solution, which is the great nutrient medium upon which plants feed, and, further, to determine the effect of absorption upon the structure of the solid portion of the soil in modifying its power to hold and maintain the soil solution for the continued use of the plant. As a result of this work it has been shown that a number of modifying factors enter into each particular case, which makes it impracticable to formulate a simple general law which will account quantitatively for the distribution of a dissolved substance between the liquid solution and the absorbing medium, although it is brought out very clearly that under the ideal conditions, where there is no change in the surface of the absorbing medium, a simple mathematical law can be predicated a priori, which law is approximately realized in practice in those cases where it is known that the least amount of change takes place in the absorbing surface. The nature of these modifying factors, and in a general way the extent to which they enter, with especial reference to soil components, has been the subject of careful investigation, the results of which are here recorded.

In general it may be said that our knowledge of the nature and character of absorption factors and their influence upon the concentration of soil solution, and upon the reactions which take place between soil components and artificially added constituents, has been materially advanced, and that the further investigation of this important line of soil studies will be more easily and more rapidly prosecuted on the basis of the work presented in this bulletin.

FRANK K. CAMERON.

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ABSORPTION BY SOILS.

INTRODUCTION.

From the standpoint of soil chemistry the absorption of material from air and from soil solution is of the first importance. The absorptive power of the soil enables it to retain the soluble salts necessary to plant life in spite of the leaching effect of rains, thus storing up soluble material from the weathering and dissolving soil grains for future needs of crops. Also it prevents the soil solution from becoming too concentrated.

Besides this holding back of nutrient soluble salts, the absorptive power of a soil has an important part in determining its physical condition. There is a relation between the quantity of soluble salts absorbed by the soil and the size and compactness of the soil-grain aggregates; and upon the size and arrangement of these soil aggregates, in turn, the optimum water content of the soil depends. The openness of a soil determines its ventilation, and thus likewise its opportunity for securing proper oxidation and for the forming of humus. The optimum water content[a] as determined by plant growth coincides in general with the percentage of moisture at which the soil has its maximum volume, and at this maximum the soil also shows its greatest openness or minimum resistance to root penetration. Thus a purely physicochemical reason is at hand for the existence of an optimum water content in soils, and we are now able to correlate several of the factors which determine the state of a soil known as "good physical condition." Likewise, through its absorptive power the soil removes from soil solution and soil atmosphere the waste products thrown off by growing roots,[b] which products are detrimental or inhibitory to continued growth.

Appreciation of these relations has come about gradually. Sand filters for purification of sea water and impure drinking water have been used at least since the time of Aristotle; the removal of salts from sea water by percolation through sand or earth filters was practiced in Bacon's day. Dr. Steven Hales announced to the Royal Society in 1739 that the first portion of sea water passed through stone cisterns was pure. Berzelius filtered salt solutions through sand and found that the salt content was more or less removed; and Matteucie determined the concentration of salt in the solution after it had passed through successive filters, and found the concentration to be successively smaller. The clarification of barnyard liquor and other colored waters by percolation through fresh clay or loam was mentioned by Sir Humphrey Davy in 1813, by Gazzeri in 1819, Lambuschini in 1830, Browner in 1836, Huxtable in 1848, Bernays in 1849, and by Thompson and Way[a] in 1850. It is especially interesting to note that as early as 1819 Gazzeri considered that loam and clay take up in their pores the soluble matters in solution and retain them to release them by degrees to the plants. In 1830 Lambuschini suggested the name *incorporation* for the fixation of dung liquor by the soil, and in 1836 Browner insisted that soils held back even the soluble salts in dung liquor.

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[a] Bul. No. 50, Bureau of Soils, U. S. Dept. of Agr., 1907.

[b] Bul. No. 28, Bureau of Soils, U. S. Dept. Agr., 1905; Farmers' Bul. No. 257, U. S. Dept. Agr., 1906; Bul. No. 40, Bureau of Soils, U. S. Dept. Agr., 1907.

Liebig found that aqueous ammonia passed through clay lost its odor, and Thompson and Huxtable verified the experiment. In 1850 Way showed that soil likewise absorbed potassium, sodium, calcium, and magnesium, not only from solutions of their hydrates, but of their salts, with both strong and weak acids, the acid remaining in solution unabsorbed and combined with other bases leached from the soil. Phosphoric acid, however, was itself absorbed. Way believed the absorption or replacement of the bases to be total, but Voelcker showed that weak solutions of ammonia could circulate in the soil and still retain some of their ammonia unabsorbed, and Peters[b] demonstrated that however weak the solution used, potassium was never completely absorbed. Frank[c] confirmed Peters's results, using the percolation method. Thus there was introduced the conception of *distribution*, the partition of a soluble substance between solid and liquid, so that no matter how small a quantity of substance be present there is a fraction of it left in solution. And the application of this principle has led to a much better understanding of the retention of soluble material by soils.

Before proceeding to a detailed consideration of the different phenomena of absorption a few precise definitions are in order. The term absorption is used in general to designate the process by which a solid or a liquid draws unto itself and retains within its structure or on its surface another solid, liquid, or gas.

The simplest case of absorption is that of mechanical absorption, or *imbibition*, such as water held by a sponge, by porous solids like brick or charcoal, by powders, including soils, and by bodies which draw liquid or vapor into their most intimate recesses and swell, as, for example, starch with water, or rubber with chloroform.

A second kind of absorption is where a solid retains another solid so that the two form a *homogeneous body* and the mixture is either a

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[a] Storer, Agriculture, 1897, I, pp. 201 and 316; also Jour. Roy. Agr. Soc., **11**, 313 and 366 (1850).

[b] Landw. Vers.-Stat., **2**, 129 (1860).

[c] Ibid., 8, 45 (1866).

definite chemical compound or a *solid solution*. The criterion of a solid solution is that when present in equilibrium with a liquid solution containing the same components a variation in the percentage of these components in the liquid is accompanied by a corresponding change in the composition of the solid phase. Thus free phosphoric acid added to a soil containing ferric hydroxide is absorbed in such a way that the more P_2O_5 there is in solution the more P_2O_5 is found in the solid ferric hydroxide—that is, the P_2O_5 forms a solid solution with the ferric hydroxide, and its composition changes with that of the liquid solution above it.[a] An even more interesting case is that of the absorption of phosphoric acid by lime. Here the P_2O_5 forms a solid solution with the CaO, the percentage of P_2O_5 in the solid phase increasing with increase of P_2O_5 in the liquid phase until a certain concentration in the liquid is reached, and further increase of P_2O_5 in the liquid causes no increase of P_2O_5 in the solid—that is, a definite compound of CaO and P_2O_5 has been formed.

A special case of absorption has been termed *adsorption*, which may be defined as the existence of a difference in concentration or density of a film adjacent to a bounding solid and the concentration or density of the mass of the liquid or gas which bathes this solid.

Whether this adsorbed film is in a liquid, solid, or gaseous state, or even loosely combined with the solid bounding medium, is not easily determined and has been the subject of much discussion. The change of state from solid to liquid and from liquid to vapor is very gradual. All the recent physical researches, dealing even with hard, polished "solid" surfaces, indicate a mobility of parts, an openness of structure, and a high power of retaining foreign material. But the ability of one body to hold another upon its surface is dependent upon the material of which each consists. So we are accustomed to say that adsorption depends upon the chemical constitution of the solid as well as of the substance adsorbed. Another way of stating the same idea is to attribute adsorption to a specific attraction between solid and adsorbed material.

This preference of one material for another is well shown by the separation of substances in solution from each other by simply percolating the liquid through an absorbent body, which takes one substance from solution, while the other passes into the filtrate. This process has been called *selective absorption* and is of very wide occurrence, although its possibilities as an analytical and technical method of separation are only beginning to be appreciated.

Throughout this paper the terms "solvent," "solute," and "absorbent" are used with the following meanings:

Solvent: A pure liquid used to dissolve some solid, liquid, or gas.

Solute: The substance dissolved by the solvent.

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[a] See Bul. No. 41, Bureau of Soils, U. S. Dept. Agr. The Action of Water and Aqueous Solutions upon Soil Phosphates. Frank K. Cameron and James M. Bell.

Absorbent: The solid body which when placed in a solution abstracts part or all of the dissolved material from the solution.

Further, the terms "gel," "sol," and "colloid" are used with special meanings:

Gel: A number of substances, such as metallic oxides, are precipitated from solutions of their soluble salts as amorphous solids. These solids frequently contain so much of the solvent from which precipitation takes place that they have a jellylike consistency, and consequently the term "gel" has been applied to them. When these gels are formed in an aqueous solution and the liquid held in combination with them is water, they are termed "hydrogels."

Sol: By proper treatment it is possible to cause these gels to redistribute or suspend themselves throughout the liquid from which they were originally precipitated. Such a resuspension of the precipitate in many cases has been found to consist of minute particles of the gel. Where this is the case the opalescent liquid thus formed is termed a "sol." Where the solvent used is water, such a suspension is termed a *hydrosol.*

A *colloid* has been defined as a material which when dissolved will not pass through certain membranes, and has been considered to be of high molecular weight and consequent complexity; a crystalline substance, on the other hand, passes through these membranes. This distinction between colloid and crystalloid is not maintained so rigidly at present, for some crystalline materials show a very slow rate of diffusion through the membranes. At present colloidal solutions are considered to be made up of minute particles in suspension. Consequently, if the absorption of materials from solution by finely divided solids is studied and the relation between this absorption and the formation of these particles into larger aggregates and their consequent settling from suspension, it is found that the general phenomena there observed are parallel to those where the much finer particles of a colloidal solution or precipitated colloid are under consideration.

The referring of various actions otherwise not clear to the presence of "colloidal material" does not now afford that satisfaction which it gave before the intimate relation between colloidal solutions and suspensions of larger particles had been recognized.

In order to bring out clearly the general application of the phenomena of absorption and the general principles derived therefrom, a number of solvents, solutes, and absorbents, in addition to soils and constituents of the soil solution, have been studied. The establishment of these general phenomena in the case of pure substances where no life process enters strengthens very greatly our certainty in their validity when they are found to hold good for such very complex materials as exist in soils and soil solutions.

RÉSUMÉ OF EARLIER WORK.

Hoffman[a] in 1858, summing up the question of removal of nutrient salts from a soil by rains, says:

> It is very probable that each soil possesses a peculiar power of retaining certain nutrient material for plants. But this power appears to have a limit, and whatever material over and above this limit remains in solution, follows the movement of this solution. In this movement of water itself there appears to be a means—at least for certain soils and certain relative positions—of returning to the earth a part of the leached soluble salts. When the rains are not heavy the water in the soil does not penetrate very deeply, and during the evaporation consequent upon hot weather the water from below is again drawn up to the surface and its soluble salts are returned to the fine soil grains.

In 1866 Frank[b] investigated the absorption of potassium chloride by soil. He used cylinders 3 inches in diameter and 3 to 6 feet long. The soil was carefully removed from the field and placed in these cylinders, keeping the same relative position of the soil layers. Distilled water was passed till only a trace of chlorine came through, as shown by a slight turbidity when silver nitrate was added. Then he placed 4 liters of potassium chloride solution, 1 gram per liter (0.1 per cent), in a flask and inverted it above the soil, so that the liquid might percolate under atmospheric pressure alone as the soil took it up, as illustrated in figure 1. He found that the salt solution drove out the water which remained in the soil, no diffusing of one liquid into the other being noticed. After he had made sure that the soil contained only salt solution, by analyzing the liquid which drained from tap No. 2, 12 inches below the surface of the soil, and finding that the same per cent of chlorine was in this liquid as in the original solution, he analyzed another portion of this same percolate and found that it contained only 9 per cent of its original potassium, 91 per cent being retained by 12 inches of soil. A similar test of the percolate from tap 3, 18 inches below the surface, showed 4.5 per cent of potassium left and 95.5 per cent absorbed. The taps lower down (4, 5, 6, etc.,) showed little further decrease in the potassium in the percolates, and even after the solution had passed through 6 feet of soil it always retained 2 to 2.5 per cent of its original potassium. So there appears to be a certain dilution of the solution—in this case 1 part in 40,000 to 50,000 parts—at which water is more effective in holding the dissolved material than the absorbing power of the soil.

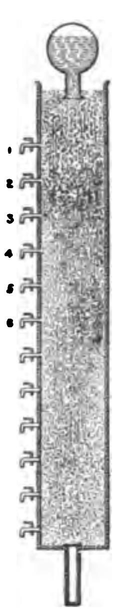

FIG. 1.—Percolation tube used by Frank in his studies on absorption.

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[a] Jahresb. Agr.-Chem., **1**, 16 (1858); see also Liebig, Ann. Chem. u. Pharm., **105**, 109 (1858); Grouven, Agron. Zeitung, 1858, p. 1; also Jahresb. Agr.-Chem., **1**, 14 (1858); Babos, Landw. Ber. v. B. (1858), p. 1.

[b] Landw. Vers.-Stat., **8**, 45 (1866).

Potassium is still more quickly absorbed from a solution of potassium sulphate, so that with a potassium sulphate solution it will not penetrate the soil so deeply as with a potassium chloride solution.

Frank found on using a solution of 1 gram pure potassium chloride and 1 gram sodium chloride to 100 parts of water that the potassium content of the percolate through 18 inches of soil still contained 18 per cent of its original potassium, as against 5 per cent (average) when no sodium chloride was present. Likewise, after passing through 4 feet of soil the percolate gave 5 per cent of the original potassium content, whereas with no sodium chloride in solution the potassium content was reduced to some 3 per cent of that in the solution added. Thus the presence of sodium chloride lowers the absorption of potassium and carries it deeper into the soil. In addition, a cylinder of earth which had been allowed to absorb potassium from a pure potassium chloride solution was percolated with distilled water till the runnings showed no potassium in solution. Then a solution of sodium chloride was passed through and potassium immediately appeared in the percolates. Frank was not at all sure that this points to a chemical substitution of potassium by sodium.

He found that the chlorine was absorbed from a sodium chloride solution percolated through earth and that most of the chlorine in the percolates was combined with sodium. It appeared to him, accordingly, that sodium chloride is not so easily decomposed by the earth as potassium chloride, and that a part of the sodium chloride is absorbed unchanged. Long-continued washing with pure water removed almost all the sodium chloride, while, as already stated, this can not be done in the case of potassium.

Next he tried the effect of sodium chloride upon the most insoluble phosphates in the soil. The upper 3 inches of soil in a cylinder filled with earth (as above described) was mixed with precipitated well-washed basic calcium phosphate and the cylinder percolated with distilled water. The filtration through these cylinders—4 to 6 feet long—took four weeks. At 12 inches below the surface only traces of phosphoric acid could be detected in the percolate; but, on the contrary, when sodium chloride solution (1 gram per liter) was passed through the soil phosphates were detected as far down in the cylinder as 4 feet and below.

Salomon[a] gives the absorption of calcium by various soils and soil constituents from several concentrations of calcium nitrate solution, to which was added sufficient ammonia to neutralize exactly the nitric acid of the calcium nitrate. The solution was placed with the soil in a flask, shaken, and allowed to stand forty-eight hours, filtered and analyzed and the absorbed calcium determined by difference. The results are given in Table I.

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[a] Landw. Vers.-Stat., 9, 351 (1867).

TABLE I.—*Absorption of calcium from amoniacal calcium nitrate solution by soils, according to Salomon.*

		Used in experiment.		CaO in 200 c.c. solution added.	CaO remaining in 200 c.c. of solution.	CaO absorbed by 100 grams soil.
		Soil.	Solution.			
		Grams.	*C.c.*	*Grams.*	*Gram.*	*Gram.*
1	Soil from Möckern	100	200	0.1	0.0788	0.0212
2	.....do	100	200	.2	.1580	.0420
3	.....do	100	200	.4	.3096	.0904
4	.....do	50	100	1.0	.8120	.1880
5	Russian black earth	100	200	.1	.0848	.0152
6	.....do	100	200	.2	.1580	.0420
7	.....do	50	100	.4	.2344	.1656
8	.....do	50	100	1.0	.5960	.4040
9	White "Kujawischer"	50	100	.2	.1292	.0708
10	.....do	50	100	.4	.2701	.1299
11	.....do	50	100	1.0	.8586	.1414
12	Black "Kujawischer"	25	50	.2	.1071	.0929
13	.....do	25	50	.5	.2862	.2138
14	.....do	25	50	1.0	.6979	.3021
15	Kaolin from Salzmunde	50	100	.2	.1743	.0257
16	.....do	50	100	.5	.4306	.0694
17	.....do	50	100	1.0	.8619	.1381
18	Tile clay	50	100	.2	.1704	.0296
19	.....do	50	100	.5	.3500	.1500
20	.....do	50	100	1.0	.7326	.2674
21	Ferric hydroxide	25	50	.2	.0490	.1510
22	.....do	25	50	1.0	.0576	.9424
23	Aluminum hydroxide	50	100	.2	.0000	.2000
24	.....do	25	50	.5	.0226	.4774
25	.....do	25	50	1.0	.309	.9691
26	Silicic acid (hydrated)	50	100	.2	.0659	.1341
27	.....do	50	100	.5	.1664	.3335
28	.....do	50	100	1.0	.2388	.7612
29	Kaolin+aluminum hydroxide, equal parts	50	100	.4	.0106	.3894
30	100 grams kaolin+25 grams ferric hydroxide	125	200	1.0	.3480	.6520
31	50 grams kaolin+50 grams ferric hydroxide	100	200	1.0	.0435	.9565
32	Soil from Möckern	50	200	1.0	.8772	[a].1228
33	Russian black earth	50	200	.5	.2184	[a].2816

[a] Effect of mass of earth used.

The behavior of the Russian black earth, which contains 9 to 15 per cent of humus, compared with those soils poor in humus, shows that the humus in the Russian black earth must be already saturated with bases. Salomon's predecessor, Pochwistneff, had already found by direct investigation that this is the case and that the black earth contains calcium humate. The soil from Möckern shows a lower absorption than the black earth for a solution containing 0.5 gram calcium oxide per liter, and both soils show the same degree of absorption for a 1-gram calcium oxide per liter solution. The other soils, as, for example, the white "Kujawischer" soil, which contains hardly a trace of humus, nevertheless show an absorption for calcium nearly equal to that of humus-rich soils, such as the black "Kujawischer" and the Russian black earth.

The similarity between the Russian black earth and the tile clay—in that both show a change in absorption with increasing concentration—suggests that the cause can not be in the humus content of the black earth. Salomon considers that such a calcium solution as was used would probably not act upon humic acid which had been already saturated with bases and would probably be changed only where free humic acid, or humic acid dissolved in carbon dioxide and alkalies, is present.

It is evident that all the solute is not withdrawn from the solutions even at low concentrations; apparently the aluminum hydroxide absorbs all the calcium from a 0.1 per cent solution, but this exception to the general rule was doubtless due to the presence of ammonium carbonate in the alumina, which precipitated the calcium as carbonate. The aluminum hydroxide was prepared from aluminum sulphate by ammonia and washed with ammonium chloride.

The white "Kujawischer" soil (entirely free from calcium) absorbed almost the same mass of calcium from a 0.2 per cent solution as from a 0.5 per cent solution. This means that the absorption capacity is limited. The black "Kujawischer" soil shows a similar tendency toward an absorption limit.

Biedermann [a] prefaces a research on absorption as follows:

> Since it has been made clear that of itself the chemical analysis of a soil can give no indication as to its value in respect to cultivation and crop yield, one is forced to study the properties of the soil in other ways, and thus it is soon discovered that the absorptive power of the soil for soluble fertilizers—the ability to fix the same and then to give them up to the plants—is of great significance for practical agriculture as well as for the interesting philosophical question, In what form do the plants obtain their nourishment from the soil?

Biedermann studied the absorption of potassium and of phosphates by soils, and he showed the magnitude of the absorption effect for a number of soils. He concludes that chalk, magnesia, and sulphuric acid do not affect absorption by the soil, and suggests that by use of a suitable solute the absorptive power of a soil may be determined—possibly by potassium phosphate. He tried potassium carbonate solution, percolating it through different soils and titrating the liquid passed through with sulphuric acid, but the results were unsatisfactory.

The quantities of potassium absorbed by different soils vary considerably, and it is certain that the magnitude of absorption is in accord with the value of a soil, although neither the quantity of bases extracted from the soil by means of ammonium tartrate-oxalate solution, nor the ferric hydroxide or aluminum hydroxide content of the soil, nor the quantity of humus in the soil—as shown by weight loss on ignition—give a certain indication of the soil's productive power.

Treutler [b] in a series of researches has studied the absorption and resolution of potassium by soils as affected by other fertilizer agencies. In all his work he used cylinders 9.7 cm. wide and 90 cm. long. Into each cylinder was shaken 4 pounds of earth (containing 85.5 per cent of fine earth), and then 0.5 pound of earth was rubbed up with the potassium salt and with the fertilizer, whose effect upon the absorption of potassium it was desired to study. The 4.5 pounds of earth had a depth of 29 cm. in the cylinder. In each experiment the earth was weighed air dry. The quantity of potassium salt was so chosen that exactly 1 gram of potassium oxide was added to the 4.5 pounds of earth. For comparison blank experiments were made, using each potassium salt alone and the cylinder then percolated with distilled water to ascertain the per cent of potassium the earth would absorb. The 4.5-pound portion of soil required 672 cm. of water to saturate it, so that in each experiment 1,672 c. c. of water were passed through the soil in order to obtain a liter of percolate. This same percolate was repassed through the soil 12 times in order to obtain the equilibrium conditions. Table II is compiled from Treutler's results:

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[a] Landw. Vers.-Stat., **11**, 1, (1869).

[b] Landw. Vers.-Stat., **12**, 184 (1869); **15**, 371 (1872).

TABLE II.—*Effect of various fertilizers upon the absorption of potassium by a soil, compiled from the results of Treutler.*

[Four and one-half pounds of earth 29 centimeters deep, percolated 12 times with the same percolate, 1,672 cubic centimeters in volume, to insure equilibrium.]

Fertilizer added in top 0.5 pound of soil.	Potassium absorbed.			
	1.849 grams K_2SO_4 added.	2.146 grams KNO_3 added.	1.583 grams KCl added.	1.467 grams K_2CO_3 added.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Bone dust, 500 grams	45.3	54.43	58.0	51,52
Bone dust, 50 grams	81.6	95.09	79.8	98.00
Humus soil, 250 grams	83.4	95.12	80.7	98.13
Cow manure, 80 grams	89.7	92.21	82.2	97.00
Sheep manure, 80 grams	93.2	89.74	90.5	90.31
Horse manure, 80 grams	93.0	93.62	91.3	85.63
Cow urine, 125 grams	96.3	90.68	91.5	94.99
Chili saltpeter, 20 grams	86.3	86.83	....	83.75
Ammonium carbonate, 20 grams	88.7	89.61	85.0	88.37
Superphosphate, 20 grams	89.6	87.90	86.1	91.98
Magnesium sulphate, 5 grams	90.2	83.52	....	96.76
Gypsum, 20 grams	90.4	90.01	88.6	93.05
Humus soil, 250 grams + $(NH_4)x(CO_3)y$, 20 grams	91.8	82.25	88.7	94.65
Water containing carbon dioxide, 1 liter	93.7	94.96	92.9	95.62
Potassium magnesium sulphate, 3.698 grams	93.9	84.29	....	89.07
Sodium chloride, 10 grams	96.4	90.90	95.4	[a] 100.00
Distilled water alone passed through soil	[b] 97.9	[a] 91.75	[b] 94.7	[a] 97.60

[a] Landw. Vers.-Stat., 15, 372 (1872).

[b] Landw. Vers.-Stat., 12, 191 (1869).

Treutler found that the greatest quantity of potassium was absorbed from the sulphate, the carbonate, chloride, and nitrate following in the order named, and he concluded, therefore, that a deeper penetration of potassium into the soil was secured by the use of potassium chloride than by the use of potassium sulphate as a fertilizer. He found, further, that the relative absorption from these two salts was not materially affected by the addition of other salts and of the common fertilizers. The absorption of the potassium from the carbonate and nitrate is more affected by other agencies than is the absorption from the sulphate or from the chloride, the absorption from the carbonate being affected to the greatest extent.

In general, the addition of other mineral salts depressed the absorption of potassium, a marked influence being noticed in the case of sodium chloride, which further brought into solution in the soil percolate noticeable quantities of magnesium salt; and for this reason Treutler concludes that sodium chloride is harmful rather than beneficial as a fertilizer.

Bone dust and superphosphate depress the absorption of potassium; and Treutler considers them especially useful on this account, as they tend to increase the concentration of potassium salts as well as of phosphoric acid and ammonia in the soil solutions. Gypsum and magnesium sulphate were found to increase the concentration of potassium in the percolate. Humus, and especially humus mixed with ammonium carbonate, appeared to decrease the absorption, which effect is attributed to the formation of large quantities of carbon dioxide from the humus.

Knop[a] includes under absorption the process of conversion of a solid first to soluble form and then the spreading of the substance upon the soil grains in such a way as to withdraw it from solution, regardless of whether chemical affinity or surface attraction is the cause of this retention or whether the substance absorbed is decomposed chemically or absorbed unchanged. He used a solution of 1 gram ammonium chloride in 208 c. c. of water to determine the absorptive power of a soil. One hundred grams of earth were taken for analysis. The nitrogen corresponding to the ammonia still left in solution was determined and the number of cubic centimeters of nitrogen absorbed by the soil taken as the measure of the absorptive power of the soil. Using this method, he found the absorption of ammonia by 38 soils which had been analyzed chemically.

In a few cases he compared the absorption of potassium with that of ammonia. For this purpose he employed an analytical procedure which has since been followed by a number of investigators. These two analytical methods for ammonia and for potassium are given in detail here, since a number of investigators have used them to express their data on the absorption by soils in terms of Knop's absorption figure, i. e., the cubic centimeters of nitrogen (as ammonia) absorbed by 100 grams of soil, from 200 c. c. of the ammonium chloride solution described above. A potassium carbonate solution was taken of such concentration that 100 c. c. contained exactly the weight of potassium equivalent to 100 c. c. of nitrogen gas. Fifty cubic centimeters of this solution plus 50 c. c. of the above ammonium chloride solution when evaporated to dryness gave all the potassium as chloride, the ammonia and carbon dioxide going off upon ignition. But when one adds 100 c. c. of the ammonium chloride solution to 50 c. c. of this potassium carbonate solution and evaporates to dryness there remains sufficient ammonium chloride to give by the nitrometer method 50 c. c. of nitrogen. This fact was made the basis for a quantitative estimation of the potassium by adding ammonium chloride to the potassium carbonate solution, evaporating, and then determining the nitrogen in the residue.

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[a] Knop's book, Die Bonitirung der Ackererde, published by H. Haessel, Leipzig, 1872, 2d edition, is not generally available. We are indebted to the Massachusetts State Experiment Station, Amherst, for the use of their copy.

Knop believed that the absorptive power of a soil was proportional to the "Aufgeschlossene Silicatbasen," i. e., such substances as ferric oxide, alumina, etc. His data, on the whole, seems to bear out this conclusion. But later investigators[a] have shown that this is by no means the sole factor to be considered; and, indeed, Knop himself admitted this. He found the absorption for one and the same soil a constant, but seems to have no clear idea of the effect of end concentration of solution upon the quantity of solute absorbed. While he recognizes that substances in a soil capable of forming well-defined chemical compounds will of course absorb from a solution the material with which they can combine, he still observes phenomena in the absorption of potassium and of ammonia which he can not explain in the ordinary chemical way. He thinks the absorption of phosphoric acid may be explained as due to chemical combination, and if it were merely a question of the absorption of caustic potash or of ammonium hydroxide he would class these also as reacting chemically with the soil. But he finds that the selective absorption—the separation of these bases from the strongest acids by soil—and the effects upon absorption produced by varying quantities of soil, of solvent, and of solute all complicate the problem so much that he can not give a simple chemical explanation of it. He shows, too, that the power of a soil to absorb moisture from the air parallels in general its absorption of ammonia from ammonium chloride solution.

Frey[b] continued the work of Knop and confirmed his results.

Pillitz[c] showed that soils possess a saturation point for ammonia absorbed from ammonium chloride solution, and Fesca[d] recognized the influence of extent of soil grain surface in determining the absorption capacity. In 1887 Kellner[e] confirmed Pillitz's experiments and from new work concludes that ammonia and potassium are absorbed in chemically equivalent quantities by soils. Kellner extracts absorbed potassium from a soil thus: The soil (20 grams) is heated with 50 c. c. saturated ammonium chloride solution for a half hour, the solution poured off, the soil washed with hot distilled water, and fresh ammonium chloride solution added to the soil. This extraction is repeated (fifteen to twenty times) until the filtered solution leaves no solid residue upon evaporation and ignition. In this manner he recovers slightly more potassium than the soil had taken up from a known potassium chloride solution. This recovery is especially interesting since Way[a] and Eichorn, Dietrich,[b] Peters,[c] and Schuhmacher[d] were all unable to substitute completely one absorbed base by another. This method of substitution used by Kellner is essentially a percolation, and recognizes in a practical way the distribution of potassium between soil and solution. He also suggests that absorbed potassium may be more firmly fixed in an insoluble form, as, for instance, by internal arrangement of the double silicates containing water.[e] He further concludes that for potassium and calcium it may be considered as settled that these elements can afford nourishment to plants only when in dissolved or in absorbed condition.

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[a] See Sachsse, Lehrbuch der Agrikulturchemie, p. 169. "Mehr als eine gans grobe Annäherung an ein Verhältniss zwischen aufgeschlossenen Silikatbasen und Absorption lässt sich nicht erwarten."

[b] Landw. Vers.-Stat., 18, 3 (1875).

[c] Zeit. anal. Chem., 14, 55, 285 (1875).

[d] Die agronomische Bodenuntersuchung und Kartirung, 1879, p. 28.

[e] Landw. Vers.-Stat., 33, 359 (1887).

Fiedler[f] has investigated the effect of sodium nitrate upon the absorption of phosphoric acid and potassium by soils. He concludes that the sodium nitrate prevents the percolating soil moisture from carrying phosphoric acid down with it to lower levels. On the other hand, potassium is less absorbed in the presence of the sodium nitrate and is carried deeper into the earth. When calcium is present in the soil in goodly quantity, this effect of sodium nitrate upon the potassium is not observed, while the sodium nitrate still is able to act upon the phosphate to prevent its removal by leaching. Fiedler suggests that as the quantity of sodium nitrate is increased more calcium nitrate is formed, and that this precipitates the phosphoric acid of the soluble phosphates as insoluble calcium phosphate.

Van Bemmelen,[g] in 1888, sums up the results of an extended research upon the absorption of soluble material from solution by soils and soil constituents as follows:

> Absorption compounds are formed from their components according to inconstant molecular ratios. They must be distinguished from chemical compounds, although they may often be rearranged into definite chemical individuals. Colloidal substances form such absorption compounds with water or other liquids, and with bases, acids, and salts when in contact with their solutions. The absorptive power of a colloid depends upon its molecular state of aggregation, and is also different for the different

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[a] Jour. Roy. Agr. Soc., **11**, 313 (1850).

[b] Jahresb. Agr. Chem., **1**, 29 (1858); **5**, 12 (1862)..

[c] Ibid., **3**, 11 (1860).

[d] Ibid., **10**, 21 (1867).

[e] Landw. Vers.-Stat., **33**, 364 (1887).

[f] Landw. Vers.-Stat., **26**, 135 (1881).

[g] Landw. Vers.-Stat., **35**, 136 (1888).

substances which it absorbs. The power of absorption decreases as the colloid holds absorbed more and more of the substance. The relation between the concentration in the colloid and the concentration in the solution at equilibrium is a complex function (still unknown) of these concentrations and of the temperature. The absorbed substances may be substituted by other substances absorbed from solution by the colloid; bases may in this manner be substituted for the bases of a salt solution. Colloids may often produce chemical decomposition of salts by their power of absorption. The soil contains colloids, colloidal silicates, iron oxide, silicic acid, and humus substances, all of which may bring about these actions.

Van Bemmelen thinks that the absorptive power of a soil is mainly to be ascribed to the colloidal oxides and silicates present in it.

Humus substances are decomposition and degradation products of carbohydrates, albuminoids, etc. Humus will absorb ammonia and organic materials to a greater or less degree. Natural humus contains nitrogen, of which a part may be driven off as ammonia by dilute potassium hydroxide; on treating further with strong potash solution ammonia is unmistakably given off anew. He states that when peat is analyzed it shows the presence of alkali bases, which for the most part must be absorbed, since the peat is lacking in mineral acids sufficient to neutralize them.

Consideration of the solubility of the humus substances shows that some exist which are of themselves soluble in water. Some, indeed, according to Van Bemmelen, may go through colloidal membranes on dialyzing, but for the most part their solubility is a colloidal solubility. They form generally opalescent liquids when they are dissolved. Frequently the solubility depends upon small masses of alkali or of ammonia. Often the humus constituents may be separated by the influence of a small mass of acid or salt or by drying, as well as in other ways changed into an insoluble modification—as is true for colloidal substances in general.

Many dissolved humus substances show the properties of a hydrogel. The substance when dissolved by an alkali and coagulated by an acid after washing out partly dissolves again, and this solution is of a colloidal nature. These humus substances form absorption complexes with acids and salts, but most easily with bases. The dissolved humus substances form with alkalies soluble complexes which may be separated by alcohol.

Heiden[a] found that peat and various preparations of the supposed humic acids when brought into solutions of chloride of potassium and chloride of ammonium remove a portion of these salts from the liquid, leaving the solutions perceptibly weaker. The removed salts were for the most part readily recovered by a small quantity of water. Schumacher[b] observed that humus artificially prepared by the action of oil of vitriol on sugar when placed in 10 times its quantity of solutions of various salts containing about 0.5 per cent of solid matter absorbed of sulphates of soda and ammonium and of chlorides of calcium and ammonium about 2 per cent, of sulphate of potash 4 per cent, and of phosphate of soda 10 per cent. Schumacher also noticed that sulphate of potash is able to expel sulphate of ammonium from so-called humic acid which has been saturated with the latter salt, but that the latter can not displace the former. In Schumacher's experiments pure water freely dissolved the salts absorbed by the supposed humic acid.[a]

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[a] Hoffmann's Jahresb., 1866, p. 29.

[b] Hoffmann's Jahresb., 1867, p. 18.

A neat experimental demonstration of the absorption of soluble material from solution was given in 1867. Humus and a weak solution of oxalic acid were placed in a beaker.[b] The humus absorbed the oxalic acid from solution, and after the humus had settled and the supernatant solution had become clear a little sack made of collodion, attached to a glass tube and filled with water and calcium carbonate, was suspended in the solution, not touching the layer of settled-out humus. The oxalic acid of the solution diffused into the collodion sack and reacted with the calcium carbonate to form insoluble calcium oxalate. Thus the concentration of the solution in oxalic acid is lowered and the absorbed oxalic acid from the humus comes again into solution, and finally the absorbed oxalic acid is practically all removed from the humus. This was shown by removing the humus and extracting with hot water. The filtrate showed no trace of oxalic acid. The humus was free from bases, so that a chemical combination could not have been formed. If the humus had been in contact with a nutrient solution, and had absorbed plant food from it, a plant whose roots were in the solution would have behaved in a similar manner, absorbing the soluble matter from solution just as did the collodion sack containing calcium carbonate.

From calcium phosphate, humus suspended in water can absorb calcium and considerable free phosphoric acid.

That plant substances and animal tissues may absorb inorganic chemical compounds accompanied even by chemical decomposition of inorganic solute is known. Consequently one may expect of the humus constituents that they are in condition to absorb whole salts and acids in small amounts. If these humus constituents are coagulated from aqueous solution by a small mass of acid or salt, they are very difficult to free of acids or salts by washing. This fact van Bemmelen considers as showing that the acid or the salt is absorbed by a colloid.[c]

According to van Bemmelen, compounds of the so-called humic acid soluble in water are obtained when the aqueous or alkaline solution of a humus substance is treated with a solution of the hydrates of the alkaline earths or salts of the alkaline earths and metallic oxides—for instance, calcium, lead, and iron, etc. These compounds are also of colloidal nature and of changing composition. The humus substance in aqueous solution is coagulated and precipitated by a small mass of salt, and may fix a certain mass of base by absorption. Even an undissolved base in a hydrogel condition may precipitate humic acid, as, for instance, the hydrogel of alumina.

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[a] Hoffmann's Jahresb., 1867, p. 18. See also Johnson, How Crops Feed, p. 172.

[b] Quoted by Schumacher, Physik der Pflanze, p. 304, Berlin, 1867.

[c] Van Bemmelen, Landw. Vers.-Stat., 35, 69 (1888).

The humus substances hold the potassium more strongly combined than the calcium, but the calcium compound is less soluble. If, therefore, humus is treated with a solution of a potassium salt, a certain mass of potassium is fixed, along with an interchange with calcium and magnesium; and if the soluble compound of humus is treated with an alkali or calcium solution, then it will form an insoluble calcium humus compound. The action of humus substances upon alkali carbonates, alkali phosphates, and, in general, salts of weak acids, is such that certain masses of alkali are absorbed with exchange for calcium and magnesium. In addition, alkali is absorbed by the insoluble humus substances, humus substance is brought into solution by the alkali thus set free, and the above mineral acids are precipitated by alkaline earths. Since, in general, the absorption of base is greater than of acid, the remaining solution has an acid reaction, although the salt was one of a strong base with a weak acid.

The decolorizing action of wood charcoal was discovered in 1791 by Lowitz,[a] and later Figuier showed the greater absorbing power of animal charcoal. Payen[b] found that charcoal could absorb lime from solution as well as coloring matter. Graham[c] ascribed this decolorization to the concentration of coloring matter upon the surface of the carbon—that is, to adsorption—a purely mechanical explanation. He found that charcoal also acts chemically upon solutions, extracting the metal from solutions. Weppen[d] found that one salt affects the absorption of another by charcoal. Birnbaum and Bombasch[e] found that boneblack absorbs a small amount of ammonia from ammonium salts and that in other cases the acid and basic radicals are absorbed, but not in equivalent proportions. Qualitative experiments by Liebermann[f] have shown that the acidity or basicity of a solution treated with charcoal changes as well as the concentration. Similar results have been obtained by Moride,[g]

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[a] See Ostwald, Stoechiometrie, 1891, p. 1093.

[b] Ann. Chim. Phys., **21**, 215 (1822).

[c] Quarterly Jour. Sci. (new series), **7**, 120 (1830); also Pogg. Ann., **19**, 139 (1830).

[d] Ann. Phys. Chem., **55**, 241 (1845); **59**, 354 (1846).

[e] Dingl. Poly. Jour., **218**, 148 (1876).

[f] Wien. Akad. Ber., **74**, 331 (1877).

[g] Compt. rend., **41**, 605 (1855).

Esprit,[a] and Heintz,[b] and Kelberin[c] has studied the absorption of hydrochloric acid by charcoal. Kroeker[d] and Lagergren[e] have used charcoal in studying the distribution of the solute between the solvent and absorbent, and the latter investigator used charcoal in studying the rate of absorption. Oechsner de Coninck[f] has shown that heavy metals are removed from solution of their salts by charcoal.

Rosenthaler and Türk[g] have studied the absorption of various pharmaceutical substances from their solutions when treated under standard conditions with different kinds of charcoal. These charcoals may be divided, according to their absorbent powers, into strongly absorbent—bone, flesh, and "vegetable blood" charcoals, in the order named—and weakly absorbent or nonabsorbent—blood, lime-wood, and spongy charcoals. For the same kind of charcoal the absorption of any substance varies with the solvent which is employed. The absorption is by far the strongest in aqueous solutions; it is less with ethyl alcohol, methyl alcohol, ethyl acetate, acetone, and least of all with chloroform solutions. The speed of absorption depends on the same factors as influence the amount of absorption, being greatest in the case of bone charcoal and aqueous solutions. The quantity of substance absorbed by a given quantity of charcoal is relatively less for concentrated solutions than for dilute solutions. All the circumstances which favor absorption act in a similar degree in resisting the reextraction of the absorbed substance. The decolorizing power of the charcoal is dependent on its absorbing power. As regards the use of charcoal for decolorizing purposes, the authors state that the charcoal must be carefully purified before use, either by repeated extraction with the solvent which is to be used or by igniting gently and washing with acid. The quantity of charcoal employed should be as small as possible. It is not necessary to heat the liquid with the charcoal; several hours' contact at the ordinary temperature will suffice. The decolorization should not, for preference, be effected in an aqueous solution, because the loss of substance by absorption is at a maximum with that solvent; the solution should be as concentrated as possible. Easily oxidizable substances should not be decolorized by animal charcoal, because this charcoal has a powerful oxidizing action; the oxidation of alkaloids is retarded by treating them in the form of salts. Blood charcoal has the strongest oxidizing action, lime-wood charcoal has hardly any. Bone and flesh charcoals can be employed in the determination of caffeine without loss of alkaloid, but in the determination of sugars, etc., in wine and other liquids charcoal should not be used unless it has been proved that no loss by absorption takes place under the conditions of the experiment. The close interdependence of the decolorizing and absorbent properties of charcoals suggests that the decolorization is due to absorption of the coloring matters. The fact that successful results can be obtained in practice depends, first, on the circumstance that the amount of coloring matter is generally only a fraction of the total substance in solution, and, second, on a selective absorption, according to which the quantity absorbed is generally proportional to the molecular weight, most coloring matters being substances of high molecular weight.

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[a] Jour. pharm., **16**, 192 (1849).

[b] Lieb. Ann., **187**, 223 (1877).

[c] See Ostwald, Lehrbuch der Allgemeine Chemie (1891) p. 1096.

[d] Uber die Adsorption gelöster Körper durch Kohle, Diss. Berlin, 1892.

[e] Bihang till K. Sv. Vet. Akad. Handl., **24**, Afd. II, No. 4 (1898).

[f] Compt. rend., **130**, 1627 (1900).

[g] Arch. Pharm., **244**, 517 (1906).

The experiments of Kellner[a] show that platinum black absorbs minute quantities of acids and alkalies, but gives them up to water on standing.

Many rock powders possess the power of absorbing the coloring matter from solutions in which the powders are suspended. The alkalinity of water in which rock powders have been in suspension has been shown in a large number of cases by Clarke.[b] Some powders, such as very finely powdered orthoclase, have been found to show no red color with phenolphthalein. This is due to the absorption of the color by the powder. A suspension of orthoclase in water which showed no color on the addition of phenolphthalein was allowed to settle, and the supernatant solution after being poured off showed a distinct red color with a further addition of phenolphthalein. When a little of the suspended material was added to the solution again the red color disappeared from the solutions, but was seen on the surface of the solid particles. The test of alkalinity of a solution by phenolphthalein can not properly be made if there are present in suspension finely divided particles which have the power of absorbing the indicator. Another substance which absorbs the phenolphthalein is magnesium ammonium phosphate.

Hulett and Duschak[c] have investigated the nature of barium sulphate precipitates, which are nearly always found to weigh too much, and attribute the results observed by them to the formation of a compound $BaCl.HSO_4$. On long standing or heating of the precipitate hydrochloric acid was given off—which is in harmony with the assumption that hydrochloric acid was absorbed on the surface of the precipitate and escaped when the area of surface was reduced. Barium sulphate precipitates have been found to absorb many compounds from solution. Vanino and Hartl[a] observed that this precipitate absorbs colloidal metals from solution, and Patten[b] observed that salts of nickel, cobalt, chromium, iron, and manganese in solution are absorbed by barium sulphate precipitates. Korte[c] has found that not only does barium sulphate absorb salts from solution, but also calcium oxalate precipitates absorb magnesium oxalate, even in the presence of ammonium chloride, and ferric hydroxide absorbs manganese hydroxide and nickel hydroxide. Ostwald[d] has called attention to similar cases.

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[a] Ann. Phys. Chem., **57**, 79 (1895).

[b] Bul. No. 167, U. S. Geol. Survey, p. 156 (1900).

[c] Zeit. anorg. Chem., **40**, 196 (1904). See also Trans. Am. Electro-Chem. Soc., **12**, 257 (1908).

Suida[e] has shown that the fixation of dyes by animal textiles (wool or silk) is due in part to the amphoteric character of the amino acids which enter into the composition of these albuminoid bodies. He has separated bodies from these complex albuminoid fibers which, like the original substance, fix acid or basic dyes, since these simpler decomposition products are themselves amino acids, $R(NH_2)(COOH)$.

Colloidal substances have the power of absorption to a very marked degree. In numerous papers[f] van Bemmelen has shown that all colloids absorb organic and inorganic compounds. They have the power of absorbing one of the constituents of an inorganic salt, leaving the solution acid or alkaline, as the case may be. The distribution of the absorbed material between water and the colloid is not constant, but depends upon the concentration of the solution.

The use of clays as absorbents has been specially valuable in technical processes, and more especially in the clarification and separation of oils. The technical literature on this subject is now enormous, but, while of the highest importance for certain commercial processes, the work which has been done adds comparatively little to our theoretical knowledge of the subject, and hence is not given in detail.

SELECTIVE ABSORPTION.

It has been found by numerous investigators that when an absorbent is brought into contact with a solution containing two or more solutes these solutes may be absorbed in very different degrees, and thus more or less complete separation of the solutes may be effected. A particularly interesting case of selective absorption is where a substance like a salt is separated into its constituent parts and either the acid or the base from which the salt is derived is absorbed to a greater extent, leaving the solution more concentrated with respect to the least-absorbed constituent. Thus, for instance, a solution of potassium chloride agitated in contact with a soil, or cotton, or carbon black, or similar materials which do not themselves react with either the base or the acid, nevertheless leaves a solution which is markedly acid. This phenomenon is particularly marked in the case of such salts as are greatly hydrolyzed when brought into contact with water.

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[a] Ber., **37**, 3620 (1904).

[b] Jour. Am. Chem. Soc., **25**, 186 (1903).

[c] Jour. Chem. Soc., **87**, 1503 (1905).

[d] Foundations of Analytical Chemistry, Trans. by McGowan, 1895, p. 26.

[e] Monatsh. Chem., **25**, 1107 (1904); **26**, 413, 855 (1905); **27**, 225 (1906); Hoppe-Seyler's Zeit. physiol. Chem., **5**, 174 (1906); C. f. the literature on dyes and amino acids given there.

[f] Landw. Vers.-Stat., **35**, 72 (1888); Jour. prakt. Chem., **23** , 324 (1881); Zeit. phys. Chem., **18**, 331 (1895); Zeit. anorg. Chem., **13**, 233 (1896); **18**, 14, 98 (1898); **23**, 111, 321 (1900); **30**, 265 (1902); **35**, 23, 338 (1904); Arch. Néer. (2), **6**, 607 (1903).

A third type of selective absorption has been observed in a few cases and designated as negative absorption—that is, there is an increase in the concentration of the solute after contact with the absorbent. This is obviously due to the fact that the solvent is taken up or absorbed to a relatively greater extent than the solute. This perhaps theoretically should not be considered as a special case, since we are yet without criteria to distinguish between solvent and solute, and it is rather a matter of convenience to consider the material in excess as the solvent.

CARBON.

SEPARATION OF SILVER FROM SILVER NITRATE.

Graham[a] studied a number of interesting cases of selective absorption. He found, for instance, that when a solution of silver nitrate was passed through powdered charcoal a separation of the salt was effected, and a subsequent examination of the charcoal disclosed the presence of metallic silver in small spangles.

EXTRACTION OF METALS FROM NEUTRAL SALT SOLUTIONS.

Esprit,[b] Moride,[c] and Heintz[d] obtained similar selective absorptions with carbon, the metal being extracted from its neutral salt solution and the resulting solution having in consequence an acid reaction.

Oechsner de Coninck[e] effected separations of the heavy metals from their solutions by percolating through charcoal. In this way iron could be quantitatively separated from solutions of its chloride.

LIBERATION OF ACID FROM NEUTRAL SALT SOLUTIONS.

Liebermann[f] found that the following salt solutions passed through animal charcoal yielded acid solutions, some of which on distillation gave the free acid: The barium salt of the acid formed by oxidizing glycerin with chromic acid, barium formate, sodium acetate, lead acetate, calcium glycollate, zinc lactate, ammonium oxalate, sodium-potassium tartrate, sodium borate (previously alkaline), trisodium phosphate (previously very alkaline), disodium phosphate, ferrous sulphate, copper sulphate, silver nitrate, and potassium acetate. The following aqueous salt solutions, however, showed no change of alkalinity or acidity, but the concentrations were less after passing through carbon: Sodium chloride, nitrate, and sulphate; potassium chloride, iodide, bromide, cyanide, sulphocyanate, and sulphate; calcium chloride, and barium chloride and nitrate. In the case of morphine acetate and caffein citrate, the first percolates contained none of the solute, but after a time the free acids came through.

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[a] Pogg. Ann., **19**, 139 (1830).

[b] Jour. Pharm., **16**, 192 (1849).

[c] Compt. rend., **41**, 605 (1855).

[d] Lieb. Ann., **187**, 227 (1877).

[e] Compt. rend., **130**, 1627 (1900).

[f] Wien. Akad. Ber., **74**, 331 (1877).

SEPARATION OF ORGANIC DYES INTO ACID AND BASIC CONSTITUENTS.

Freundlich and Losev[a] have found that basic dyes in aqueous solution are split by charcoal, the base being absorbed and the acid remaining as such in solution. The absorbents silk, wool, and cotton act similarly. The color base of crystal violet present in adsorbed condition upon the surface of the charcoal is a glittering brown-violet color; it is insoluble in water, but dissolves in acids, alcohols, pyridine, etc., with a blue-violet color. The color-base of "Neufuchsin" appears green on the surface of the charcoal and dissolves in acids, alcohols, pyridine, etc., with a red color. The body, described by Baeyer, obtained when fuchsine is treated with cold aqueous sodium hydroxide, and which is regarded as a polymeric imine base, resembles in many respects the material adsorbed on the charcoal. From crystal violet, also, there was obtained, by adding cold sodium hydroxide solution, a brown-violet amorphous powder difficultly soluble in water, but readily soluble in alcohols and pyridine with a blue-violet color. On these experimental grounds Freundlich and Losev suggest that amorphous polymerization products of the color base are adsorbed and form with carbon or other adsorbent, colloid complexes. In the case of the dyes patent-blue and orange IV, there is no splitting of the dye salt by charcoal on adsorption.

GELATINE.

SEPARATION OF ALUMINA FROM ITS SALTS.

Lummiere and Seyewetz[b] found that the separation of alumina from its salts could be effected by using gelatine as an absorbent.

SOIL.

ABSORPTION OF FERTILIZERS.

Selective absorption of different fertilizers by the soil was early studied by Frank[c] and by Treutler,[d] as described above.

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[a] Zeit. phys. Chem., **59**, 284 (1907).

[b] Bul. Soc. Chim., **35**, 676 (1906).

[c] Landw. Vers.-Stat., **8**, 45 (1866).

[d] Ibid., **12**, 184 (1869); **15**, 371 (1872).

PAPER.

ABSORPTION OF NEUTRAL SALTS AND DYES.

Schönbein[a] dipped strips of paper into different solutions, determined the heights to which the solution and the pure solvent rose in the paper, and observed their ratio. Since the paper absorbs the salt or organic coloring matter from solution, the higher layers are more and more dilute till near the top of the wetted paper one finds pure solvent. Göppelsröder[b] has used this selective property of paper to separate different dyes. He obtained a rose-red substance, probably fuchsine, from commercial azuline, which lost its violet tint and became a purer blue. Bayley[c] noticed that when drops of certain solutions fell on filter paper there was a separation into a water ring surrounding a solution more concentrated than the original solution. He found, too, that with increasing dilution the amount of separation became greater, and that increase in temperature and looseness of texture lowered the absorptive effect.

Lloyd[d] has determined the relative separations of different salts and finds that with sodium chloride no separation occurs, while sulphuric acid and solutions of ferric sulphate and of salts of silver, lead, and mercury suffer more or less separation into water and a stronger solution. Using the same method, Trey[e] has effected a separation of cadmium from copper. The copper cadmium solution is made alkaline with ammonia and diluted until the blue color is scarcely visible. Several drops of the solution are allowed to spread into a filter paper, and when the wet paper is subjected to ammonium sulphide vapor three rings appear—an outer water ring, which has been robbed of soluble material by the absorbing action of the paper; a yellow ring of cadmium sulphide precipitated from the soluble cadmium salt which was less strongly absorbed by the paper than the copper salt; and in the center is a black circle of mixed copper and cadmium sulphides, the copper salt being held back by the absorptive effect of the paper, while the liquid as a whole follows its normal tendency to spread, and thus the water appears to travel faster in the filter paper than the cadmium salt solution; the cadmium salt seems to spread slower than the water, but faster than the copper solution. Vriens[f] passed dilute nitric acid through several filter papers and found the absorption of acid, as shown by decrease in concentration, to be proportional to the number of filter papers used. J. J. Thomson[a] has made similar observations with filter paper. Fischer and Schmidner[b] allowed a saturated solution of ferrous ammonium sulphate to diffuse upwards through rolls of filter paper inside of a glass tube, and found that the proportion of the constituents in the filter paper was the same as in the double salt, although the absolute amounts had been diminished.

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[a] Verhandlung d. Naturforsch. Ges. in Basel, **3**, 249, (1861-63); Pogg. Ann., **114**, 275 (1861).

[b] Ibid., **3**, 263 (1861–63); Mitteil d. techn. Gewerbemuseums, Wien. (1889).

[c] Jour. Chem. Soc., **33**, 304 (1876).

[d] Chem. News, **51**, 51 (1885).

[e] Zeit. anal. Chem., **37**, 743 (1898).

[f] Zeit. phys. Chem., **31**, 230 (1899).

Cameron and Bell[c] have studied the rise of solutions and of pure solvents in paper, using aqueous solutions of malachite green, eosine, and potassium chloride, and mixtures of the two dye solutions and of eosine and potassium chloride. The rise of water and of solution is well represented by the equation $y^n = Kt$, where y is the height to which the paper is wetted, t is the time, and n and K are constants. They were able to separate the dyes from each other and from potassium chloride and showed that the presence of potassium chloride decreased markedly the height to which eosine rose in the paper in a given time.

COTTON.

ABSORPTION OF POTASH FROM POTASSIUM CHLORIDE SOLUTIONS.

These same investigators[d] wrapped strips of sensitive blue litmus paper in absorbent cotton moistened with distilled water freed from carbon dioxide and showing no reaction with a very sensitive specimen of litmus. A slight pressure was applied in order to insure intimate contact. In the course of about fifteen minutes the litmus paper had become decidedly pink, apparently showing an acid reaction. Two wads of this same cotton were placed in beakers, one containing a solution of potassium chloride neutral to litmus and the other containing potassium acetate with a slight but sufficient excess of acetic acid to redden litmus. Within a few minutes the supernatant liquor in the beaker containing potassium chloride had become distinctly acid, as shown by the further addition of litmus, while the supernatant solution in the beaker containing the acetate had become distinctly alkaline to both litmus and phenolphthalein. It is obvious, therefore, that the reddening of the litmus was a true absorption effect.

Absorbent cotton has the power of absorbing potash from a potassium chloride solution. A tube which was filled with absorbent cotton was placed in a beaker containing a solution of potassium chloride neutral to litmus. The solution after passing through the cotton was decidedly acid. But when potassium acetate was substituted for potassium chloride, even though a slight excess of acid was present, the solution after passing through the cotton was alkaline to litmus or phenolphthalein. Similar results were obtained by merely agitating wads of cotton in solutions of the reagents.

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[a] Applications of Dynamics to Physics and Chemistry (1888), p. 191.

[b] Ann. Chem. (Liebig), **272**, 156 (1893.)

[c] The Mineral Constituents of the Soil Solution, Bul. No. 30, Bureau of Soils, U. S. Dept. of Agr., (1905); Jour. Phys. Chem., **10**, 658 (1906).

[d] Bul. 30, Bureau of Soils, Dept. Agr. (1905).

BARIUM SULPHATE.

ABSORPTION OF SODA FROM SODIUM SULPHATE SOLUTION.

In another experiment a solution of sodium sulphate neutral to litmus was added to a solution of barium chloride neutral to litmus in the cold. After the precipitate subsided the supernatant solution was found to be acid. The experiment was repeated, using potassium sulphate instead of sodium sulphate, and the supernatant solution was alkaline. These experiments indicate that the barium sulphate precipitate absorbs some of the constituents of the solution, that the relative amount of acid and alkali absorbed may be varied, and that the absorbing medium may act very differently toward bases or acids.

KAOLIN.

E. C. Sullivan,[a] using magnesium and sodium chloride solutions, repeated Kohler's[b] experiments on the filtration of salt solutions through kaolin and confirmed his result that the filtrate from a neutral salt solution is slightly acid. Kohler attributed this effect to a selective concentration of dissolved substance—an adsorption of the base. But Sullivan accounts for this acidity in the filtrate by an exchange of the magnesium and sodium of these salts in part for the iron and aluminum of the kaolin, the salts of the latter metals undergoing extensive hydrolysis in dilute solution. The acidity observed is of the same order of magnitude as the quantity of trivalent bases found in dilute copper sulphate solution after contact with kaolin. He further suggests that the acidity of a salt solution after filtration through a substance, such as kaolin, through which the liquid diffuses but slowly, may be due to some extent to the greater velocity of diffusion of the acid constituent of the salt, which is present owing to hydrolysis, while the base is present (for salts of heavy metals) to a greater or less extent in the colloidal condition and colloids are marked by their very slow rate of diffusion.

COPPER HYDROXIDE.

Tommasi[c] found that the solutions of such neutral salts as sodium chloride and sulphate and potassium chloride and bromide become basic when precipitated copper hydroxide is added to the solution. The acid is absorbed by the copper hydroxide, which then becomes green in color.

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[a] The Interaction Between Minerals and Water Solutions, Bul. 312, U. S. Geol. Survey, p. 8, 1907.

[b] Zeit. prakt. Geol., **11**, 49 (1903).

[c] Compt. rend., **92**, 453 (1881).

NEGATIVE ABSORPTION.

CHARCOAL.

Lagergren[a] found that either solvent or solute could be absorbed, or, in other words, that the solution could become more concentrated or less concentrated. Thus solutions of sodium chloride, potassium chloride, ammonium chloride, and ammonium bromide became more concentrated after contact with charcoal, while sodium nitrate, potassium nitrate, sodium sulphate, potassium sulphate, and ammonium nitrate become less concentrated. This author states that he could find no evidence of any change in alkalinity or acidity of the solutions. This behavior has been ascribed by the author to an increase in the density at the surface of the solid—an increase in density which involves an increase in pressure. If, therefore, an increase of pressure increases the solubility, or, in other words, if solubility is accompanied by a decrease of volume, there will be a positive absorption; but under reverse conditions there will be a negative absorption. Lagergren has calculated the degree of absorption from the surface of the solid exposed, the radius of molecular action, and the density of water under different pressures. The results of the calculation for absorption of ammonium chloride and the observed absorption agree fairly well.

KAOLIN AND GLASS WOOL.

Parallel results have been obtained where the absorbing material is kaolin and glass wool, the negative absorption of sodium chloride by kaolin having been found by van Bemmelen.[b]

CLAY.

White china clay has been used as an absorbing medium by Cushman,[c] who finds a considerable decrease in the basic ions from solutions of ammonium chloride, barium chloride, and aluminum sulphate. The data indicate that there may have been also a negative absorption of the sulphuric acid, i. e., a considerable absorption of water from aluminum sulphate solutions, which then became more concentrated with sulphuric acid, although the author thinks the phenomenon is due entirely to the fact that, owing to hydrolysis, free acid necessarily exists in a solution of a salt of a trivalent base.

SELECTIVE ABSORPTION OF DYES.

Dyes forming colloidal solutions are extremely sensitive to electrolytes in regard to their adsorption[d], the effect being proportional to the size of the colloidal particles. In the case of electro-negative dyes (Congo-red) cations facilitate absorption, anions depress it; with electro-positive dyes (toluidine-blue) the opposite is seen, but in both cases the effect of anions is small. Salts of the heavy metals which form positively charged colloidal hydroxides powerfully promote adsorption of Congo-red. The facilitating ion is carried down with the dye. The presence of a stable colloid, such as gelatine, protects Congo-red from the action of electrolytes. When gelatine is precipitated by tannin, its adsorbed electrolytes are split off. In the process of blood-clotting there is a diminution of electrical conductivity, ions (probably of calcium) disappearing from solution. There is no evidence of a sudden separation of electrolytes in the tissues at the moment of death, although there is a gradual one when a living tissue is warmed from 11° to 56°. In the action of rennet on milk there is a slight increase in conductivity, an additional fact showing this process to be quite different from blood-clotting. In all probability rennet action is only an expression of pepsin action in neutral or faintly alkaline media (Pawloff).

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[a] Bihang till K. Sv. Vet. Akad. Handl., **24**, Afd. II. No. 4 (1898).

[b] Zeit. anorg. Chem., **23**, 321 (1900).

[c] Bul. No. 92, Bureau of Chemistry, U. S. Dept. Agr., 1905, p. 18.

[d] Bayliss, Biochem. Jour., **1**, 175 (1906).

Recently Craw[a] has studied the filtration of crystalloids and colloids through Martin's gelatine filter (a Pasteur-Chamberland filter the pores of which are filled with solid gelatine) and finds it highly but not completely permeable for such crystalloids as sodium chloride, potassium iodide, and butyric acid. The work of Waymouth Reid showing that this filter is slightly permeable to colloids was confirmed. As filtration proceeds the crystalloids show an increasing concentration in the filtrate, whereas the colloids gradually decrease to zero and are completely retained by the filter. The presence of one substance in solution often affects the rate of filtration of another. The permeability depends, too, upon the gelatine used. Thus a filter prepared with 15 per cent gelatine solution is less permeable to certain colloids than a filter prepared with 7.5 per cent gelatine solution, and formalized gelatine is less permeable to sodium chloride than ordinary gelatine.

APPLICATION OF SELECTIVE ABSORPTION IN PHYSIOLOGY.

The theories of absorption have been applied to physiology in a research on the neutralization by lysin and by antilysin and on diffusion through gelatine filters.[b]

SELECTIVE ABSORPTION OF DYES BY SOILS.

Sjollema[c] found that different solid soil constituents have very different absorptive power for dyes. He classifies as colloids those substances which are colored by organic dyes, and thus excludes undecomposed mineral fragments and quartz which are not tinted by the dyes he used. The definition of a colloid thus implied is so inclusive as to bring such substances as carbon black, platinum black, and all other amorphous substances, as well as powdered crystalline substances, under the head of colloids, and consequently it becomes meaningless. It has been shown[a] by Cameron and Patten that gentian violet (*gentianin*) is adsorbed by quartz to a considerable extent, and this same dye colors other soil grains, crystalline as well as amorphous.

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[a] Proc. Roy. Soc., B 77, 311 (1906).

[b] Craw. Zeit. phys. Chem., 52, 585 (1905).

[c] Jour. f. Landw., 53, 67 (1905).

Cameron and Bell[b] found that solutions of dyes poured through soils always yield clear water for the first runnings. When eosin solution is used the dye soon appears in the percolate, but soils retain methylene blue, malachite green, gentian violet, and some other dyes with remarkable tenacity. Separations of a mixture of eosin and methylene blue were made by percolation, the methylene blue being completely retained by the soil, while the eosin was comparatively readily removed by washing. It was shown, too, that for any particular solution of a dye the various soils had a definite absorption limit; that is, if the solution is poured on a given mass of soil slowly and at a very uniform rate there is a point at which the soil will cease to absorb the dye, and the solution will come through unchanged. Fairly good duplicate determinations for the absorptive power of any particular soil can be made in this way. Heavy soils absorb generally more than light soils, and black, red, or dark-brown soils more than those of lighter color. The presence of humus adds very considerably to the absorptive power of a soil. In some cases, at least, the absorption of one dye by a soil does not materially reduce its capacity for retaining a second dye. It was found, too, that while a dye might be so firmly held by a soil as to resist removal on leaching, the soil nevertheless gave up dye to filter paper and to some kinds of blotting paper. Likewise, absorbed dye may be removed unchanged in some instances by use of a different solvent—for example, alcohol—when further leaching with water is practically of no avail. These authors state that, in general, papers are better absorbents for dyes than soils, but, on the other hand, some solutes, such as alkalies, are generally absorbed more powerfully by soils than by papers. This has an important bearing on the common practice of testing the reaction of a soil with moist litmus paper. Blue litmus, as is well known, is the sodium salt of the red dye. In aqueous solution it must be considerably hydrolized, so that when a paper saturated with it is brought into intimate contact with a soil the base is absorbed more readily by the soil and the remaining acid more readily by the paper, with the consequence that the latter becomes red. This explanation of the reddening of litmus paper by soils was confirmed by other experiments.

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[a] Jour. Phys. Chem., **11**, 581 (1907); Trans. Am. Electrochem. Soc., **10**, 67 (1906).

[b] The Mineral Constituents of the Soil, Bul. 30, Bureau of Soils, U. S. Dept. of Agr , 1905, p. 57.

SELECTIVE ABSORPTION AND THE ACIDITY TEST FOR SOILS.

Cameron and Bell further suggest that it might be argued from these experiments that the only test as to the presence of an acid in a soil is the formation of an acid solution when extracted with water. It is true that this is the only satisfactory criterion which suggests itself. As the experiments just cited show, solid and other absorbent substances can and do absorb acids, some more than others, and it is quite possible that an absorbed acid, which was not easily removed from a soil by water, might be removed by paper, if paper were the better absorber for that particular acid. It is well, therefore, to view with caution the prevalent notions as to the wide distribution of acid soils founded on a very uncertain criterion, and especially in view of the fact that the great majority of soils yield aqueous extracts which on heating in platinum show alkaline reactions. Most of our field crops can withstand a fairly high concentration of acid; but clover[a] is especially sensitive, being inhibited in growth by concentrations less than twenty-thousandth normal (N/20,000). Yet cases have been observed where clover was found growing well in soils apparently very acid, the true explanation being undoubtedly that the supposed estimation of acidity was, in fact, a measurement of the absorptive capacity of the soil.

Furthermore, it is probably fallacious to assume that the acidity of a soil can be estimated by adding calcium hydrate, ammonia, or other alkalies in solution until the soil will turn red litmus paper blue when the paper is brought into contact with the soil, since it has been clearly shown that most soils absorb these substances much more effectively than does litmus paper. If these solutions be added to the soil slowly (for absorption is not an instantaneous process, but requires appreciable time to attain equilibrium), it frequently is astonishing how much alkali can be taken up before an alkaline reaction can be detected by the test paper—a fact repeatedly observed by various investigators, but the significance of which had not hitherto been recognized.

GENERAL STATEMENT CONCERNING SELECTIVE ABSORPTION BY SOILS.

Regarding the degree to which the different constituents of the soil solution are absorbed, several generalizations can be made; but from the foregoing data and discussion it will be evident that each soil will exert its own peculiar effect in retaining soluble matter, and that, while we may seek to classify a fertilizer as adding potassium or nitrates or phosphates to the soil, the *form* or *salt* in which the fertilizer is added will affect its absorption by soil.

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[a] Cameron and Breazeale, Jour. Phys. Chem., 8, 1 (1904).

Of the basic radicals, potassium is most strongly bound by the soil. If a soil is saturated with potassium, then one may replace the more recently absorbed potassium by other bases merely by treating the soil repeatedly with a solution of another solute, for the potassium is distributed each time between the soil and solution, and of course when the solution is removed from contact with the soil the potassium is withdrawn, too, and can exercise no further effect upon the equilibrium. Meanwhile the soil is absorbing the base or bases in these solutions applied to the soil to remove potassium. In effect we have replaced potassium by another base or bases; but it by no means follows that we may have here a case of chemical exchange by a rearrangement of definite compounds, especially as the replacement need not follow the chemical equivalence of the bases involved. This predominant retention of potassium by soils is undoubtedly the main reason why potassium is so little in evidence among the soluble salts of alkali soils—salts which have come up through the lower layers of soil and finally been concentrated near the surface, sodium and calcium salts passing on up to the surface, and, to a less extent, the magnesium salts also. It is true that in general the magnesium silicates are quite readily soluble and much hydrolyzed by water, but magnesium is absorbed to a much greater extent than calcium or sodium, although to a lesser extent than potassium.

ABSORPTION FROM VARIOUS SOLVENTS.

PICRIC ACID IN WATER, ALCOHOL, AND BENZENE.

The experiments by Walker and Appleyard[a] on absorption by silk have shown that while picric acid is absorbed by silk from solutions in water and alcohol, yet in benzene solution there was no absorption. The nature of the solvent plays, therefore, an important rôle. The relative solubilities of picric acid in the three solvents do not throw any light on the absorptive power from the different solvents, for the solubility of picric acid in benzene lies between the solubility in water and that in alcohol.

DYES IN PETROLEUM, BENZENE, XYLENE, CARBON TETRACHLORIDE, AND CARBON DISULPHIDE.

Tsvett[b] has shown that many dyes dissolved in light petroleum, benzene, xylene, carbon tetrachloride, or carbon disulphide are precipitated by powdered substances, from which they may be extracted by alcohol, ether, acetone, or chloroform. There is further an adsorption series in which the substances can replace each other on the absorbent. When a mixed solution, as, for instance, chlorophyll dissolved in carbon disulphide, is filtered through a column of precipitated calcium carbonate, the dyes are precipitated, but mutually replace each other and arrange themselves according to the adsorption series in the direction of the stream. If any zone is not pure, it can be extracted and the adsorption repeated until the desired degree of purity is attained.

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[a] Jour. Chem. Soc., **69**, 1334 (1896).

[b] Chem. Centr., 1906, ii, 1286; from Ber. deutsch. bot. Ges., **24**, 384–393.

MAGNITUDE OF ABSORPTION IN DIFFERENT SOLVENTS.

Rosenthaler and Türk,[a] in studying the effect of the solvent upon the degree of absorption, found that it is greatest from aqueous solutions. The absorption is less from solutions in ethyl alcohol, methyl alcohol, ethyl acetate, acetone, and chloroform, in the order named.

Freundlich, in his recent paper on absorption, has compared the absorption for a number of different solvents, and for dilute solution it appears to have the same order of magnitude in all of the different solvents; but, while in the same order of magnitude, there are really differences, which become more pronounced as the concentration increases, and are widely different in strong solutions.

DISTRIBUTION.

The earlier investigators appear to have had no true conception of the distribution of a substance between the liquid and solid material. Salomon[b] agrees with Liebig that absorption is purely physical in nature, but does not consider the concentration of the end solution left above the solid.

Biedermann[c] also plots as abscissa the quantity of soil per hundred parts of solution and as ordinate the percentage of solute absorbed from solution. This is a very useful and practical method of representing results, but fails to give a clear idea of the phenomena of distribution, which is tacitly assumed in Biedermann's work.

POTASSIUM BETWEEN SOIL AND SOLUTION.

Peters's[d] results on the absorption of potassium chloride by a soil have been recalculated in Table III to show the quantities of potassium in unit quantities of a solution and a soil. He neglected, however, the chlorine; but it is altogether likely that less of it would have been found absorbed than corresponds with the absorbed potassium. It is safe, therefore, to assume that Peters's analytical data give a representative distribution curve for the basic radical potassium between a soil and water. To bring out more clearly the enormous effect exercised by the soil in withdrawing soluble material from solution, the percentage of potassium absorbed by the soil from solution is given for each concentration in the accompanying table. It will be seen that this absorptive effect is nearly twice as great with dilute solution as in the strongest solution used, varying from 94 per cent of the total potassium present in the dilute solution to 54.9 per cent for a solution 20 times stronger.

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[a] Arch. Pharm., **244**, 517 (1906).

[b] Landw. Vers.-Stat., **9**, 351 (1867).

[c] Landw. Vers.-Stat., **11**, 1 (1869).

[d] Landw. Vers.-Stat., **2**, 129 (1860).

TABLE III.—*Distribution of potassium between soil and solution of potassium chloride, according to Peters.*

Potassium per kilo soil.	Potassium per liter of solution.	Total potassium present absorbed by soil.	Potassium per kilo soil.	Potassium per liter of solution.	Total potassium present absorbed by soil.
Grams.	*Gram.*	*Per cent.*	*Grams.*	*Grams.*	*Per cent.*
1.011	0.0648	94.0	1.390	0.127	91.6
1.096	.0628	94.5	1.453	.203	87.9
1.168	.0677	89.2	1.511	.361	80.7
1.238	.0797	94.0	1.579	.679	70.3
1.328	.089	93.8	1.610	1.310	54.9

CALCIUM BETWEEN SOIL AND SOLUTION.

Peters has also determined the quantity of calcium extracted from the soil by the same solutions which were being studied with respect to the absorption of potassium. He found that calcium is distributed in a manner nearly analogous to potassium, and that the curve for the distribution of calcium between soil and water has apparently the same general form as that for potassium. This observation indicates that the absorption of two solutes may proceed almost independently of each other, at least when the concentrations of both are low.

HYDROCHLORIC ACID BETWEEN CARBON BLACK AND SOLUTION.

When carbon black is shaken with an aqueous solution of hydrochloric acid, Kelberin[a] found that there is a perfectly definite distribution ratio; the results could be duplicated to within a fraction of 1 per cent.

INCONSTANCY OF DISTRIBUTION RATIO.

Kroeker[b] studied the relation between absorption and time of contact, quantity of carbon, and concentration of solution, and found that the distribution ratio between carbon and solution is not constant, but that relatively more is absorbed from dilute solutions than from strong. Schmidt[c], using Van Bemmelen's data[d] has sought to show that the distribution ratio of potassium sulphate, potassium nitrate, potassium chloride, sulphuric acid, hydrochloric acid, and nitric acid was constant. This result has been contested by Van Bemmelen,[a] who points out that the distribution ratio of a substance between solid and liquid need not necessarily be constant in the case of equilibrium between solid and liquid solutions.

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[a] See Ostwald, Lehrbuch der allgemeine Chemie (1891), p. 1096.

[b] Über die Adsorption gelöster Körper durch Kohle, Dis., Berlin (1892).

[c] Zeit. phys. Chem., **15**, 56 (1894).

[d] Jour. prakt. Chem., **131**, 324 (1881).

DISTRIBUTION FORMULAS.

A number of investigators[b] have advanced formulas to express the distribution of a solute between a solvent and an absorbing medium. These expressions have been generally suggested by the apparent analogy to the distribution of the solute between two immiscible solvents, for which two general equations have been proposed.

If c be the concentration of the solute in one solvent and c_1 the concentration of the other, then when there is no association of solute in either solvent the distribution is described by the formula $c/c_1 = K$; but if there be association of solute in either solvent, the formula becomes $\frac{c^n}{c_1} = K$. K is a constant for any standard conditions of temperature.

Ostwald[c] has proposed this same form of equation slightly modified, $x/m = \alpha\ C^{\frac{1}{p}}$, where x is the total mass of solute absorbed and m is the mass of the absorbent; C is the concentration of the solution, and p and α are constants.

This exponential formula has been found to hold more or less well for a number of cases of absorption, of which a few will be cited. Thus Schmidt[d] found it held for the absorption of iodine and several acids by charcoal, but it did not hold for the absorption of picric acid by cellulose or of eosine or malachite green by silk. Küster[e] found such a relation held for the absorption of iodine by starch.

Walker and Appleyard[f] have studied a case of unusual interest. They found that the distribution of picric acid between water and silk was described by the formula $\frac{S}{W^{\frac{1}{2.7}}} = 35.5$, where S represented concentration of the dye in the silk and W the concentration in water. This would indicate that at the concentration studied the molecule of picric acid in the water solution is 2.7 times as large as that represented by the formula $C_6H_2(NO_2)_3OH$, at least; but this is negatived by the cryoscopic measurements of the osmotic pressure and of the conductivities of aqueous solutions of picric acid.

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[a] Zeit. phys. Chem., **18**, 331 (1895).

[b] Schmidt, Zeit. phys. Chem., **15**, 60 (1894); Küster, Annalen, **288**, 360 (1894); Walker and Appleyard, Jour. Chem. Soc., **69**, 1334 (1896); Biltz, Ber. deutsch. chem. Ges., **37**, 1766 (1900); **38**, 2963, 2973, 4143 (1905); Zacharias, Zeit. phys. Chem., **39**, 468 (1901).

[c] Lehrbuch der Allgemeine Chemie II. (2 Aufl.), 232.

[d] Zeit. phys. Chem., **15**, 60 (1894).

[e] Annalen, **288**, 360 (1894).

[f] Jour. Chem. Soc., **69**, 1334 (1896).

Biltz[a] has studied several similar cases. An especially interesting one is the absorption of alizarin by ferric oxide, the distribution being described by an exponential formula, but the curve representing it not going through the origin. That is, the concentration of the solution must be above a certain value before any absorption on the solid can take place. Similar cases, as, for instance, in the absorption of phosphates from solution by soils, have been observed in this laboratory.

Freundlich[b] has added to Ostwald's equation the concept that the total quantity of solute present in the system has an effect upon the equilibrium—though the explanation for this is not yet at hand—and his empirical equation, derived from Ostwald's, takes the form $\lambda = \frac{V}{m} ln\left(\frac{a}{a-x}\right)$, where λ is a constant, V is the volume of solution, m the mass of absorbent, a the total solute in the system, and x the total quantity of solute obsorbed. Freundlich restricts this formula to dilute solutions and finds that it does not hold for solutions which conduct electricity well.

Travers[c] objects to Freundlich's statement that adsorption is independent of the solid adsorbent, the solute, or the solvent used, and, in addition, makes the point that a rigid distinction between crystalline solid solutions and highly viscous liquid solutions, such as glass, should be made. According to Travers, many cases of absorption which Freundlich would class as purely adsorption effects are in reality highly viscous liquid solutions formed at the surface of the adsorbing solid.

Freundlich[d] in his answer to Travers states that he has not thought that the *magnitude* of the adsorption effect is independent of the solid adsorbent, the solute, and the solvent, but merely that the same solid adsorbs different solutes from solution in the same relative quantities from different solvents.

Travers also takes exception to Freundlich's statement that the magnitude of adsorption is independent of the temperature. Freundlich admits that, broadly speaking, Travers's criticism is justified. Freundlich means merely to indicate that the temperature effect is so slight as to render unnecessary the use of a thermostat in the measurements made by himself.

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[a] Ber. deutsch. chem. Ges., **37**, 1766, 3138 (1904); **38**, 2963, 2973, 4143 (1905). Nach. K. Ges. Wiss. Göttingen, Math.-Phys. Klasse, **1**, 1 (1904); **1**, 1 (1905); **3**, 1 (1905), with Kurt Utescher.

[b] Zeit. phys. Chem., **57**, 385 (1906).

[c] Zeit. Phys. Chem., **61**, 241 (1907).

[d] Zeit. Phys. Chem., **61**, 249 (1907).

Hedin[a] has shown that charcoal absorbs trypsin almost completely from dilute solution, and as the concentration of trypsin increases the charcoal gradually becomes saturated. Arguing from Freundlich's[b] treatment of adsorption, Hedin concludes that this behavior of trypsin is different from that of adsorbed crystalloids, in that the trypsin shows a specific attraction for the charcoal, the first portions adsorbed being so strongly bound as to suggest an irreversible process. But in reality Hedin's observation with trypsin agrees with numerous systems where the adsorbed solute is a crystalloid.[c]

SULPHURIC AND HYDROCHLORIC ACIDS BETWEEN TEXTILES AND SOLUTIONS.

Vignon and Mollard[d] have shown the distribution of sulphuric and of hydrochloric acids between their respective aqueous solutions and the textiles unbleached silk, ungummed silk (soire décreusée), cotton, and linen. They find that cotton does not absorb these acids, but silk and linen take up relatively more acid from dilute than from concentrated solution, the coefficient of distribution $\frac{C_2}{C_1}$ increasing greatly as the acids are diluted, and decreasing slightly with rise in temperature. Equilibrium is established within one hour in those systems where the strength of acid was in round numbers from 1 per cent to 0.1 per cent. From 100 c. c. to 400 c. c. of solution was maintained in contact with 10 grams of the textile absorbent. This research establishes the fact of distribution in these systems, but the data is insufficient to give the function $\phi\ (C_2) = C_1$, even approximately.[e]

SALTS BETWEEN GELATINE AND SOLUTION.

Bayliss[f] has found that the curve of electrical conductivity of successive distilled water extracts of gelatine is a hyperbola. It is therefore impossible to wash out all the electrolytes except by an infinite number of changes of distilled water, each change removing a less percentage than the previous one; in other words, the electrolytes are present in an absorbed form. When the gelatine is washed nearly free from such admixtures and is placed in solutions of electrolytes, it again absorbs them, and so the conductivity of the solution is diminished. But it must not be taken as established that an absorbed solute is unable to contribute to the electrical conductivity of the system in which it exists. It has been shown by Patten[a] that soil grains which have absorbed alkali carbonates, when in aqueous suspension, add very greatly to the electrical conductivity, and when removed by centrifuging take with them the adsorbed or absorbed material, leaving the supernatant solution lower in conductivity than before. Similarly soils made up to paste with water or salt solution show an electrical conductivity due in part to salt which is adsorbed (or absorbed) and is very resistant to removal by leaching.[b]

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[a] Hoppe-Seyler's Zeit. physiol. Chem., **5**, 504 (1907); see also Hedin, Bio.-Chem. Jour., **2**. Biltz, Zeit. phys. Chem., **47**, 615 (1904); Nernst, Zeit. Elektrochem., **10**, 377 (1904); Craw, Zeit. phys. Chem., **52**, 569 (1905).

[b] Zeit. phys. Chem., **57**, 385 (1906).

[c] Freundlich's restriction of the validity of his formula to *dilute solution* and to *solutes which do not yield conducting solutions* tacitly admits the very point Hedin is making, i. e., that adsorption is a specific effect which depends *primarily* upon the composition of the adsorbent, of the solute, and of the solvent. The lowering or raising of the surface tension, *solid-liquid*, upon which Freundlich bases his treatment, is controlled by the composition of the solid and of the liquid which constitute the liquid-solid surface.

[d] Bul. Soc. Chim. (3), **36**, 1304 (1906); Compt. rend., **143**, 550 (1906); see also Knecht, Rawson, Löwenthal, Handbuch der Färbung von Spinnfassern.

[e] See also Vignon, Bul. Soc. Chim. (4), **1**, **2**, 273 (1907) on the relation of the electrical conductivity of the dye solution to its efficiency in coloring.

[f] Bio.-Chem. Jour., **1**, 175 (1906).

FERRIC CHLORIDE BETWEEN FERRIC HYDROXIDE AND SOLUTION.

Duclaux[c] opposes the contention of Nicolardot and Wyrouboff that the formation of a compound $Fe_2(OH)_6 \frac{1}{150} Fe_2Cl_6$ limits the possibility of removing chloride from colloidal ferric hydroxide. Duclaux has obtained by dialysis a ferric hydroxide containing less than one-third of the amount of chloride implied by the above formula, and sees no reason why the removal of chloride should not be carried further.

DEFINITIONS.

MAXIMUM ABSORPTIVE CAPACITY.

The maximum amount of a solute which an absorbent may remove from solution is, under any standard conditions of temperature, a perfectly definite quantity, characteristic of the absorbent, and is a measure of what may be defined as the "maximum absorptive capacity" of an absorbent. This maximum amount of solute can not, however, be absorbed from a solution of any concentration whatever, as is shown by equilibrium experiments,[d] but only from a solution which is saturated with respect to the solute and at the same time in equilibrium with the absorbent. Practically this case could only be realized when some of the solute is present as a solid phase, and such a system has generally but little interest, owing to the difficulty of distinguishing between the absorbed and nonabsorbed solid. It is, therefore, more convenient to estimate the maximum absorptive capacity of an absorbent by extrapolating from data obtained with solutions somewhat below saturation.

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[a] Electrochem. and Met. Ind. **5**, 257 (1907).

[b] Whitney and Means, Division of Soils, U. S. Dept. Agr., Bul. 8, 1897.

[c] Compt. rend. **143**, 296 (1906).

[d] Cameron and Bell, Bul. No. 30, Bureau of Soils, U. S. Dept. Agr. 1905; Schreiner and Failyer, Bul. No. 32, Bureau of Soils, U. S. Dept. Agr. 1906; Patten, Trans. Am. Electrochem. Soc., **10**, 67 (1906).

SPECIFIC ABSORPTIVE CAPACITY.

From a solution containing less solute than is required to saturate it an absorbent can remove a quantity less than that which measures its maximum absorptive capacity, but a quantity which is nevertheless perfectly definite for any given concentration of solution. This quantity may be defined as the specific absorption with respect to that particular solution.

Thus a solution of potassium chloride containing 500 parts per million of potassium chloride when brought into contact with a soil will lose potassium chloride, as the soil absorbs it, at a speed which gradually decreases till the salt reaches a final distribution between soil and solution. The weight of potassium chloride absorbed at a given temperature by 1 gram of soil represents the specific absorptive capacity of the soil for that particular salt at that particular concentration of the salt. This concentration is not the original concentration of solution—500 parts per million of potassium chloride—but is the final concentration reached after the absorption has been completed. If by a slight alteration of other conditions, such as temperature, the soil absorbs temporarily more salt than when the chosen temperature is again reached, the solution will remove the excess of absorbed salt from the soil and reduce the quantity of potassium chloride remaining in the soil to its absorptive capacity for the original conditions. In other words, absorption is a reversible phenomenon.

GENTIAN VIOLET DYE BETWEEN SOIL AND SOLUTION.

It is significant that those substances which are prominent as fertilizer constituents, namely, potassium, calcium, ammonia, phosphoric acid, and proteid organic matter, are substances which are markedly absorbed by soils. From the increasing knowledge of the effect of adsorbing surfaces upon the chemical reactions which might ordinarily be expected to take place among these various soil constituents, it is evident that such reactions may be and probably are very much modified when they take place in the presence of the adsorbing surfaces. In studying the distribution of an added solute between a soil and water there is difficulty in obtaining complete data when the soil already contains the solute in question. There is no method of determining absolutely the quantity of any soluble material in a soil which has already been absorbed on the soil grains, and even though the amount of solute present in the water added to the soil be measured exactly, the total amount present as absorbed material can not be ascertained.

To determine the character of this distribution more readily, water-soluble bodies have been used which are not contained in the soil naturally, and which are not appreciably changed by contact with the soil. Thus there are known the quantities of solute, of the soil, and of the water, and by varying the weight of solute a series of systems in equilibrium are obtained and the distribution of solute between water and soil can be examined quantitatively. When the character of the distribution is thus determined, a criterion is obtained for comparison with the less exact data of the distribution observed with soluble bodies which commonly exist in the soil, such as potassium salts, nitrates, phosphates, or water-soluble organic matter. Similar equilibrium experiments were made using fine quartz flour instead of soil to eliminate the effect of (1) the soluble material already present in the soil and (2) of the organic matter in the soil, which latter exerts so large an absorbing effect upon the solute as to mask the distribution of this solute between the mineral components of the soil and the solution.

The dye gentian violet has been found particularly well adapted to studying distribution, because it is changed very slightly, if at all, by contact with the soils used or with quartz flour, and because it can be readily estimated colorimetrically to within a fraction of a part in a million of solution. It is a basic dye (gentianin), represented by the formula $(CH_3)_2N.C_6H_3:SCl.N:C_6H_3.NH_2$, and is analogous in that respect to ammonia bases in general and to some fermented manures. The sample of gentian violet used gave characteristic reactions, viz: (1) Dilute aqueous acids, as hydrochloric or nitric acids, turn the aqueous dye from a violet to green; (2) concentrated sulphuric acid dissolves the dye, forming a yellowish-green solution, and (3) aqueous sodium hydroxide gives a violet color. The solubility of gentian violet in water at 25° C. was found to be 6.81 per cent of solution by weight. The experiments were carried out at room temperature which varied but little from 25° C.

One hundred gram portions of each soil were placed in strong glass bottles of some 225 c. c. capacity, with 150 c. c. of dye solution, agitated in a shaker for several days, placed in a centrifuge and whirled for several hours, and a small portion of the liquid withdrawn from each and the dye content estimated colorimetrically. The bottles were then replaced in the shaker, again centrifuged, and the dye in solution again determined. This was repeated till equilibrium had been reached, which usually required about a week's time.

By a separate experiment it was found that 100 grams Marshall silt loam absorb 4 c.c. of water from a saturated atmosphere at 29° C. This was taken as representing the volume of water which is extracted from the solution when brought into contact with this soil. So, in effect, the volume of solution for which the concentration of dye is determined is not 150 c.c.—the volume of liquid added—but 146 c.c. Similarly, 100 grams Hagerstown loam absorbs 4.5 c.c. of water from a saturated atmosphere at 29° C., and accordingly this value was used in calculating the concentration of the solutions after absorption. The quartz flour used absorbed 0.8 c.c. water under the same conditions; but as this correction affects the distribution curve by less than 1 per cent, it is neglected.

Table IV gives the experimental data for the distribution of gentian violet between soil and water. The first column shows the total quantity of dye added; the weight of dye withdrawn from solution per kilo of soil is shown in the second column for Marshall silt loam, a representative fertile soil, and the grams of dye remaining in a liter of solution in the third column. The distribution for Hagerstown loam, another fertile soil, is given similarly in the fourth and fifth columns, and for fine quartz flour in the sixth and seventh columns.

Table IV.—*The distribution of gentian violet between soils and solution.*

[100 grams soil and 150 c.c. solution.]

Dye added.	Distribution.					
	Marshall silt loam.		Hagerstown loam.		Quartz flour.	
	Dye per kilo soil.	Dye per liter solution.	Dye per kilo soil.	Dye per liter solution.	Dye per kilo soil.	Dye per liter solution.
Grams.	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*	*Grams.*
0.005					0.06	Trace.
.015					.14	0.0001
.075					.743	.0040
.100					.984	.0108
.200			1.9996	0.00023	1.901	.066
.300	3.00	Trace.			2.66	.224
.40			3.9998	.00140	2.89	.740
.50	4.85	0.0001	4.9996	.00250	2.95	1.370
.70					2.97	2.668
1.00	9.999	.00083	9.9825	.0120	2.93	4.710
1.50			14.95	.0325		
2.00	19.99	.006	19.817	.1250		
2.50	24.97	.020			2.90	14.75
3.00	29.91	.060	20.45	6.525		
3.20	31.89	.070				
4.00	37.00	2.050	20.25	13.500		

When the concentration of the dye left in solution is taken as abscissa and the concentration in soil as ordinate, curves resembling the parabola are obtained. By extrapolating these curves the maximum absorptive capacity of the soil for gentian violet may be found: Marshall silt loam, 38. grams dye per kilo of soil; Hagerstown loam, 20.45 grams dye per kilo; quartz flour, 2.97 grams dye per kilo. The absorption capacities are in the ratio 113: 61: 1, and show that each soil has its own absorptive capacity. The soil grain area of Marshall silt loam is very nearly the same as that of Hagerstown loam when calculated on the basis of their mechanical analysis, and yet the Marshall soil absorbs nearly twice the quantity of dye taken up by the Hagerstown soil. Again, both of these soils have an area presented by their grains nearly twice as great as the surface offered by the same weight of the quartz flour used, and yet the quartz has by no means half the absorptive capacity of either of the soils. The presence of organic matter is undoubtedly a very important factor in determining the magnitude of the absorption; but this absorption of dye by quartz shows that the mineral constituents of a soil, as well as the organic matter it contains, enter in to determine its absorptive capacity. It is certain, moreover, that mineral constituents other than gelatinized products of hydrolysis are capable of absorbing soluble bodies from the soil solution to a marked extent.

Considering the concentrations of dye when the soil has nearly reached its maximum absorptive capacity, it will be seen in Table IV that Marshall silt loam abstracted from solution 92.5 per cent of the total dye added; the Hagerstown loam, 51.1 per cent; and the quartz flour, 59 per cent. At lower concentrations of dye in solution the soils absorbed relatively more dye, and although the dye is truly distributed between soil and solution the soil holds so large a portion of dye that for practical purposes the dye is all absorbed. Thus for 0.5 gram dye added the Marshall silt loam absorbed 97 per cent; the Hagerstown loam, 99.99 per cent; and the quartz flour, 59 per cent of the dye. When only 0.075 gram dye is added, the quartz flour absorbs 99 per cent, leaving only 1 per cent in solution. Consequently it is clear that absorption experiments carried on over a limited range of concentrations may lead to false conclusions regarding the distribution. These experiments further emphasize the fact that a soil may hold a relatively large quantity of water-soluble material even in contact with a very dilute aqueous solution.

EOSINE DYE BETWEEN QUARTZ FLOUR AND SOLUTION.

Table V gives the data for the distribution of sodium eosine between quartz flour and water. Here the absorptive capacity of the quartz for eosine does not tend to a limiting value—at these concentrations—as it does for gentian violet, but the absorption of eosine is nearly proportional to the quantity of eosine in solution, the distribution curve being not quite a straight line. Examples of linear distribution are known. For instance, Gaubert[a] observed it for the absorption of methylene blue by crystals of phthalic acid deposited from solution in the dye when the solution is cooled, and for the absorption of the same dye by crystals of nitrate of urea. And Van Bemmelen[b] has given an interesting case in the absorption of potassium chloride by stannic oxide.

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[a] Compt. rend., **142**, 936 (1906).

[b] Zeit. anorg. Chem., **23**, 113 (1900).

TABLE V.—*Distribution of eosine between quartz flour and solution.*

[50 grams quartz and 75 c. c. solution.]

Dye added.	Distribution.		Dye added.	Distribution.	
	Dye absorbed per kilo quartz.	Dye per liter of solution.		Dye absorbed per kilo quartz.	Dye per liter of solution.
Gram.	*Gram.*	*Gram.*	*Gram.*	*Grams.*	*Grams.*
0.00242	0.009	0.027	0.075	0.348	0.768
.0075	.0135	.091	.75	4.2	7.200
.0248	.085	.274			

MANURE EXTRACT BETWEEN SOIL AND SOLUTION.

To study the absorption of the soluble organic bodies in manures, several concentrations of a well fermented and matured extract were allowed to stand in contact with soils, with frequent shaking, for two weeks at room temperature, 25° C. Then the supernatant liquid was poured off, centrifuged, evaporated to dryness in a steam bath, then in a water oven, and weighed; ignited, weighed, and the organic matter gotten by difference. The quantity of organic matter in the original manure-extract solution was determined similarly.

TABLE VI.—*Distribution of manure extract between soil and solution.*

[500 grams soil and 2,000 c. c. solution.]

Organic matter in added extract.	Hagerstown loam.		Marshall silt loam.		Norfolk sand.	
	Organic matter absorbed per kilo soil.	Organic matter per liter solution.	Organic matter absorbed per kilo soil.	Organic matter per liter solution.	Organic matter absorbed per kilo soil.	Organic matter per liter solution.
Grams.	*Grams.*	*Gram.*	*Gram.*	*Gram.*	*Gram.*	*Grams.*
0.2940	0.068	0.133	....	....	−0.129	0.1792
.5880	.366	.203	−0.109	0.321	− .100	.3192
1.176	.721	.403	.354	.500	.077	.5687
2.350	1.180	.880	.885	.954	.440	1.0650

Table VI contains data for Hagerstown loam, Marshall silt loam, and Norfolk sand. A correction for the volume of water absorbed on the soil grains was rejected here, as it amounts to less than 1 per cent, and the data serve to show the general trend of the distribution. As there is some organic matter already present in the soil, the absorption appears negative for low concentrations of manure extract, since the organic matter comes out of the soil and increases the total quantity present in solution. For Hagerstown loam the maximum absorptive capacity was found by extrapolation of the distribution curve to be approximately 1,700 parts per million. This means that with very great concentration of manure in solution 1 kilo of this soil would absorb 1.7 grams of soluble manure from the extract and no more. The data does not admit of calculating the maximum absorptive capacity for the other two soils, but a comparison of the soils on the basis of the highest quantity of manure absorbed by each gives a ratio of 2.7:2:1, in the order: Hagerstown loam, Marshall silt loam, and Norfolk sand. Here the order of the absorptive capacity is the reverse of that found for gentian violet as shown in Table IV, where Marshall silt loam had nearly twice the absorptive power found for the Hagerstown loam.

RELATION OF DISTRIBUTION TO THE USE OF FERTILIZERS.

This series of experiments is important in showing that absorption is dependent as much on the nature of the solute as on that of the absorbent. It further indicates the probable futility of attempting to select empirically a dye with which quantitative measurements might be made to determine the absorptive power of a soil for manures or fertilizers, or to determine its relative crop-producing power.

The experiments with gentian violet, together with those using manure, in Tables IV and VI, show that when fertilizers are applied to a soil relatively less and less soluble matter is absorbed from the fertilizer as more and more fertilizer is added to the same area. But on any given tract the *percentage* of fertilizer absorbed is greatest where the least fertilizer is used.

The usual application of fertilizers, however, does not raise the concentration of the soil solution appreciably. This is due to the fact that soils in the field can still absorb far more of the fertilizer constituents, and the conditions are represented by the steep portion of a distribution curve, in which region the soil absorbs large quantities of soluble material, leaving the solution very little different from the original soil solution.

Several of the cases given above for the distribution of a solute between water and soil can be represented by straight lines, that is, they can be described by a linear function of the form $C/C_1=K$. In what appears to be the more general type of distribution, however, the data do not accord well with the equation $C^n/C_1=K$, but with equations of a more complex form; in fact, for some distribution curves, when the logarithms of C and C_1 are taken and plotted, a curved line results, showing that *no exponential equation* describes this particular distribution curve. As these complex equations have no special significance and are purely empirical, they are not given here. One reason for these deviations from the simpler forms of the distribution equation was apparent in the marked changes in the state of aggregation or "flocculation"[a] of the soil particles induced by different concentrations of the solute in the aqueous solutions. In the absorption of eosine by quartz, where the distribution was nearly linear, there was no flocculation of the absorbing grains which could be observed; but the same quartz flour was flocculated when absorbing gentian violet, and very differently at different concentrations of dye. Moreover, the extent of the flocculation with increasing amount of dye went through a maximum, so that no simple formula could be expected to hold for the distribution curve. The soils studied showed similar flocculation phenomena. The foregoing data and considerations lead to the following conclusions:

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[a] Patten, Trans. Am. Electrochem. Soc. **10**, 67 (1906.)

(1) The distribution of solute between solvent and absorbent presents in general the same characteristics with soils as with other absorbents.

(2) For any series of soils or other absorbents the order of the absorptive capacities for one solute may be entirely different from the order for another solute.

(3) With one and the same soil or other absorbent the distribution function may be linear for one solute and asymptotic for another.

(4) Generally when soils are the absorbents the change of surface or "flocculation" introduces a modifying factor and the form of the distribution equation is rendered more complex.

EFFECT OF TEMPERATURE UPON DISTRIBUTION.

Biedermann[a] studied the effect of temperature upon absorption from solution. His results are not concordant, but are nevertheless what might have been expected when the effect of temperature upon humus and upon the various soil constituents, such as calcium carbonate, are considered. In general, for phosphates, the higher the temperature, up to 100° C., the greater the absorption, and after boiling for fifteen minutes still more solute was fixed by the soil. There are exceptions to this rule, where the absorption is less at higher temperatures; for potassium the absorption decreased with rise in temperature for five out of nine soils.

Bayliss[b] has further shown that the rate at which Congo-red is taken up by paper is accelerated by rise of temperature, but the total amount taken up when equilibrium is reached is less the higher the temperature; the temperature coefficient of the reaction velocity is very low, so that Nernst's theory as to the part taken by diffusion in heterogeneous reactions seems to apply to adsorption. At low temperatures, equilibrium is attained slowly; at room temperature, twenty-four hours is necessary. The adsorption complex of gelatine and inorganic electrolytes is also dissociated as the temperature rises, and no evidence of heat production in adsorption is obtained. The reaction between Congo-red and paper is reversible; so also is that between gelatine and electrolytes. It is, however, noticed that raising the temperature rapidly to 100° C. tends to fix Congo-red in paper.

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[a] Landw. Vers.-Stat., 11, 1 (1869).

[b] Biochem. Jour., 1, 175 (1906).

Draper and Wilson[a] have shown[b] that "bleu de nuit" may be absorbed by silk in two different manners, depending upon the temperature at which the dyeing takes place. Above 40° the dyed fabrics are much more resistant; at 15° the dyed fabrics "fade out" by a treatment with "soap solution" or with alcohol. When the temperature of the bath is raised, a part of the dye is fixed more firmly. These experiments have been extended to acid dyes. The silk dyed with anthracene red, acid 3B, employing 0.25 per cent of the dye in a solution of acetic acid, 0.2 per cent, offered a resistance to "soap solution" greater according to the temperature. If one makes the treatment with a solution of 1 per cent of neutral soap solution heated to 55° C. and allows an immersion of thirty minutes, the following results are obtained:

TABLE VII.—*Effect of temperature upon absorption according to Draper and Wilson.*

Temperature of the bath.	Dye remaining upon the absorbent.	Temperature of the bath.	Dye remaining upon the absorbent.
°C.	*Per cent.*	*°C.*	*Per cent.*
18.5	0.002	75	0.13
40	.01	90	.18
60	.11		

RATE OF ABSORPTION.

FORMULA EXPRESSING RATE OF ABSORPTION.

The simplest assumption that can be made is that the rate of absorption is proportional to the quantity of solute which the absorbent may yet take up; that is, to the difference between the specific absorptive capacity as defined on page 43 in this bulletin and the amount of solute already taken up. If in time t, the absorbent has taken up the amount of solute, y, while its specific absorptive capacity for a solution of that particular concentration is A, then the above assumption can be formulated thus:

$$\frac{dy}{dt} = K(A - y)$$

where K is the constant of proportionality for the particular absorbent and solution under standard conditions. In the following paragraphs a few typical cases will be described for various absorbents, including soils.

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[a] Jour. Soc. Chem. ind., **26**, 667 (1907).

[b] Jour. Soc. Dyers and Colorists, **22**, No. 9.

In testing this rate equation with the observed data, it will be more convenient to use the integrated form, namely,

$$\log (A-y) - Kt = \log A$$

which is a linear function with respect to $\log (A-y)$ and t. Since no special significance attaches to the constant K, Briggsian logarithms may be used for convenience. From inspection of this integrated equation it is evident that when the values $\log (A-y)$ are plotted against t a straight line results if the original differential equation, $\frac{dy}{dt} = K(A-y)$, correctly describes the rate of absorption.

EXPERIMENTAL TESTS OF FORMULA.

RATE OF ABSORPTION OF POTASSIUM BY A SOIL.

Peters[a] has determined the rate at which a soil absorbs potassium from an aqueous solution of potassium chloride. He does not give the temperature, but states that the experiments were carried out at Tharand in the summer of 1860 at room temperature. His results are given in Table VIII, where t represents the time in hours; y, the grams potassium oxide absorbed by 100 grams of soil; and $\log (A-y)$, the value calculated from A, 0.2168—the specific absorptive capacity of the soil for the end concentration of solution—less the value of y at each time given in the table under t.

When $\log (A-y)$ is plotted against t, the graph is not a straight line; and, in addition, $\log A$ as estimated by extrapolating the curve is less than the value of $\log A$ as found by experiment. Consequently it follows that the formula $\frac{dy}{dt} = K(A-y)$ does not describe the actual rate of absorption observed by Peters.

TABLE VIII.—*Rate of absorption of potassium oxide by a soil, according to C. Peters.*

[100 grams soil and 250 c. c. of 0.05 /N potassium chloride solution.]

Time.	K_2O absorbed=y.	Log$(A-y)$.	Time.	K_2O absorbed=y.	Log$(A-y)$.
Hours.	*Gram.*		*Hours.*	*Gram.*	
0.25	0.1417	$\bar{2}.814$	8	0.1860	$\bar{2}.499$
2	.1571	$\bar{2}.776$	24	.1990	$\bar{2}.251$
4	.1600	$\bar{2}.679$	48	.2168	....

RATE OF ABSORPTION OF OXALIC ACID BY ANIMAL CHARCOAL.

Lagergren[b] has determined the rate at which animal charcoal absorbs oxalic acid, and, using the reaction velocity equation of the first order $\frac{dy}{dt} = K(A-y)$, he has calculated a series of values of y, which are given together with those for t and y in Table IX. A is taken as the maximum quantity of oxalic acid absorbed. His calculated values do not agree with the experimental values of y sufficiently well to warrant the use of this equation.

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[a] Landw. Vers.-Stat., 2, 127 (1860).

[b] Bihang K. Sv. Vet. Akad. Handl., Band 24, Afd. II, No. 4, ii (1899).

TABLE IX.—*Rate of absorption of oxalic acid by charcoal, according to Lagergren.*

[Five grams charcoal and 10 c. c. of solution containing 4.241 grams oxalic acid per liter.]

Time, t.	y—oxalic acid absorbed.	Calculated value of y.	Time, t.	y—oxalic acid absorbed.	Calculated value of y.
Minutes.	*Gram.*	*Gram.*	*Minutes.*	*Gram.*	*Gram.*
5	0.046	0.042	180	0.245	....
10	.090	.076	360	.227	....
30	.151	.163	2,880	.249	....
60	.198	.215			

RATE OF ABSORPTION FROM PERCOLATING SOLUTIONS.

Schreiner and Failyer[a] have studied the rate at which phosphates and potassium are absorbed from solution passing through typical soils. A solution of definite concentration was percolated through soils, maintaining the rate of percolation constant by an automatic device, and determinations were made of the concentrations of solute, which increased in the successive percolates. It was found that each soil had its own specific absorbing power and that the process of absorption, considered as a volume rate, gave very regular curves when the quantity of phosphate absorbed was plotted against the total volume of solution which had been percolated. It was shown that the volume rate of absorption was well described by the differential equation

$$\frac{dy}{dv} = K(A-y)$$

where A is the "specific absorptive capacity" of the soil for phosphates in equilibrium with the solution, y is the quantity of phosphate which the soil has taken up from solution after v c. c. of that solution has passed through the soil, and K is a constant—the velocity constant. As the liquid passes from top to bottom each layer exerts its absorbing power upon weaker and weaker solution, and consequently the rate equation

$$\frac{dy}{dv} = K(A-y)$$

is a summation of all these various rates of absorption.

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[a] Bul. No. 32, Bureau of Soils, U. S. Dept. Agr. 1906; Jour. Phys. Chem., **10**, 239, 361 (1906). Compare, Calugareanu and Henry, Compt. rend. Soc. Biol., **58**, 579 (1901). Diffusion of dye stuffs through gelatine.

RATE OF PERCOLATION THROUGH SOILS.

Seelheim[a] has examined quantitatively the factors which determine the rate of percolation through sand, clay, and calcium carbonate, and finds that Poiseuille's formula, $Q = C/L$, holds for all three solids. A mixture of two sands, one having grains small enough to lodge in the interstices between the grains of the other, gives very nearly (about 1.2 times greater) the percolation rate of the smaller grained sand. But where the two sands have grains more nearly of the same size, the percolation rate is the average of that for each sand separately. The rate of flow is directly proportional to the head of water and inversely to the thickness of the soil layer. Where several layers of soil are superposed, the speed of percolation is essentially that of the least permeable layer. The acceleration in flow due to increase in temperature was determined, and an interpolation formula, calculated by means of least squares, is given for the sand, clay, and chalk used.

RATE OF MOVEMENT OF LIQUIDS THROUGH CAPILLARY TUBES, AND THROUGH PAPER AND POROUS MEDIA.

The work of Cameron and Bell[b] on the rate of movement of liquids through capillary tubes and through paper and porous media gives a slightly different treatment of the rate of absorption during percolation. In their first paper an empirical equation was proposed to describe the movement of water and of aqueous solutions through blotting paper and through soils:

$$y^n = Kt$$

where y represents the distance through which the liquid has moved in the time, t, and n and K are constants depending upon the temperature and the specific substances. The second paper places this empirical equation upon a rational basis by deriving it from the formula of Poiseuille[c] for the movement of a liquid from one level to another through a capillary tube: $Q = C\frac{HD^4}{L}$ where Q is the quantity of liquid passed through in unit time; H is the difference in level, or "head;" D and L are the diameter and length of the tube, respectively; and C is a constant. This equation may be applied to the advance or retreat of water in a capillary tube only when the assumption is made that the energy gained or lost with change of velocity (the "velocity head") is negligible in comparison with the energy gained or lost in the change of level of the water or in the friction against the walls of the tube. This formula was found to hold very well for the movement of several pure solvents through capillary tubes.

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[a] Zeit. anal. Chem., **19**, 387 (1880).

[b] Bul. No. 30, p. 46, Bureau of Soils, U. S. Dept. of Agr. 1905; Jour. Phys. Chem., **10**, 658 (1906).

[c] Ann. Chim. Phys. (3), **7**, 50 (1843).

Several series of experiments were made by Bell and Cameron using blotting paper and soils with water, aqueous potassium chloride solution, and aqueous sodium eosine, indigo-carmine, and coralline solutions, and the formula was found to hold in every case, with the restrictions that the acceleration be negligible in comparison with the velocity and that the length of the capillary soil tubes be great in comparison with their diameters. And, in addition, they have shown that this equation describes the movement through soils and paper of solutions which suffer change during the process. Both the advance of the solute and of water in the medium conform to this formula.

RELATION OF DISTRIBUTION TO RATE OF ABSORPTION FROM A PERCOLATING SOLUTION.

These rate-of-advance studies of Cameron and Bell are related to the percolation studies of Schreiner and Failyer. The latter maintained the rate of flow constant and plotted the total quantity of solute absorbed against the volume of solution percolated. It will require a long period of time to bring the lower layers of soil to anything like saturation with respect to the solute in question, so that throughout the percolation experiment there will be a different concentration of solution in contact with each layer of soil from top to bottom of the percolation tube.

The rate of selective advance in soils for indigo carmine and water through the Penn loam, for coralline and water through the Penn loam, and for coralline and water through the Podunk fine sandy loam shows that the advance of the dye is slower than that of the water, and is different for each dye. This means, of course, that the absorption effect exerted by the soil upon the solution robs it of nearly all the dye, until a point on the distribution curve is reached where the solution can retain sufficient dye to carry it along by percolation to the next layer of absorbent. Thus we are not in reality studying the rate of flow of the dye or of the dye solution in these experiments, but rather the retaining ability of the various absorbent materials for the dye as its solution percolates. When the absorbent material is fairly well saturated with the dye, the rate of flow will differ,[a] but not greatly, from that of water, save as the addition of distilled water changes the distribution and thus induces a flocculation or deflocculation of the grains of the absorbent, thus altering the channels in the soil and the diameters of the capillary soil tubes.

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[a] Krakow, Jour. Landw., 48, 209 (1900), on comparing pure water and solutions side by side, found that the water moved more rapidly through a soil. Briggs and Lapham, Bul. No. 19, Bureau of Soils, U. S. Dept. Agr. 1902, p. 6, made the same observation, which they attribute to the greater viscosity of the solutions.

The absorption curves of Schreiner and Failyer are necessarily asymptotic, since the soil can absorb only a limited weight of salt from any given solution. Consequently their curves might be expected to fit some equation in which the dependent variable tends to a limiting value. This was found to be the case, the formula $\frac{dy}{dv} = K(A-y)$ serving remarkably well to describe their experimental results and others obtained in this laboratory.

The same consideration applies to the rate studies of absorption in general, viz, that there is a limit to the quantity which an absorbent can take up and retain under equilibrium conditions; therefore all curves plotted with quantity of substance absorbed as ordinate, y, and time of absorption, t, as abscissa, must necessarily tend to an upper limit for y. Consequently no exponential equation of the form $y^n = Kt$ can exactly describe absorption rate curves. For, when the time is infinite, the absorption, y, likewise is infinite; and this is contrary to experience.

Similarly in the rate-of-advance studies: The formula $y^n = Kt$ postulates that when $t = \infty$ the height of the liquid in the soil shall be infinite. This, again, is contrary to experience, the capillary water rising until its weight balances that of the capillary effect. But the formula was developed correctly enough for the advance or retreat of liquid in a horizontal capillary tube where y for all practical purposes is infinite, and the driving force, the capillary column of liquid, remains constant. With blotting paper, too, the formula was found to hold for short distances whether the paper was in a horizontal position with $y = \infty$; or held vertically with y approaching a limit. The application of this formula, then, to vertical columns of soil and blotting paper is justifiable, in that it enables us to handle and compare and analyze experimental data in a more satisfactory manner than by merely plotting the curves. But it should be borne in mind that the formula $y^n = Kt$ can not rigidly express any function which tends to a limiting value. This caution is emphasized here, since a number of rate curves are described by this formula for a limited range.

ENERGY CHANGES.

In general the treatment of energy change takes the form of measuring the change produced in properties of one substance by action upon it of a second. The energy in a body that is available for producing changes in another substance, or substances, other than heat is called the free energy. It is different at different temperatures, since the heat-capacity or energy-capacity of a body changes with the temperature.

When a body adsorbs another, one may expect several different energy changes, mainly—

(1) In cohesion and in surface energy.

(2) In work done on expansion or contraction of volume.

(3) Electrical effects; such as static charges on surfaces and upon suspended particles, and change in potential difference where metals are immersed in electrolytes.

(4) Heat effects; heat evolved or absorbed due to change in heat capacity, and due to a rearrangement of the whole system.

TEMPERATURE RISE CAUSED BY MOISTENING POWDERS.

Pouillet[a] observed a rise in temperature when various powders were moistened by different liquids using for this purpose—water, oil, alcohol, and ethyl acetate. As absorbents he used finely divided metals, metallic oxides, powdered glass, clay, and a number of organic substances.

A number of investigators have measured the rise in temperature occasioned by the absorption of various vapors by dry soils and other absorbents. A discussion with citations of this literature has recently been given,[b] and need not be repeated here.

CHANGE IN DENSITY OF ABSORBED LIQUIDS.

Hassenfratz[c] claimed that a substance such as glass after being powdered showed a smaller specific gravity than before, and that the adherence of air to the powder does not account for the phenomenon. But he gives one experiment *using the same sample of glass powder* in which the density obtained on weighing the glass under water in an evacuated flask was greater for the powdered glass than for the same glass in one sheet. Since this agrees with the results of later investigators, it is very likely that the other observations of Hassenfratz—where he found a lower density for the glass in powder form—were affected by incomplete removal of the absorbed gases from the glass. He has, however, shown very well by these experiments that a powder placed in a liquid and thoroughly stirred will retain a considerable quantity of gas, and that the last traces of this absorbed gas are very difficult to remove, even when the liquid containing the powder is placed in a vacuum.

In the case of water wetting a powder, Junk[d] found that above 4° C. there was an increase in temperature, and below 4° C. a decrease in temperature. This result is attributed to an increase in density at the surface of the powder, which above 4° C. would tend to increase the temperature of the mass of the liquid, and below 4° C. would decrease the temperature. Meissner,[a] however, has more recently found an increase in temperature at 0° C.

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[a] Ann. Chim. Phys., **20,** 141 (1822); Gilbert's Ann., **73,** 356 (1823).

[b] Bul. No. 51, Bureau of Soils, U. S. Dept. Agr.; Trans. Am. Electrochem. Soc. **11,** 387, 1907.

[c] Gilbert's Ann. **1,** 396 (1799).

[d] Pogg. Ann., **125,** 292 (1865).

ESTIMATION OF THE PRESSURE IN ADSORBED LIQUIDS.

Lagergren[b] has calculated the pressure of water at the surface of a solid consequent upon the increase in density, and finds a pressure upward of 6,000 atmospheres. Young[c] estimated its value for water at 23,000 atmospheres, while Lord Rayleigh[d] mentions with approval a hypothesis of Dupré, which leads to the value 25,000 atmospheres by a deduction from the dynamical equivalent of the latent heat of evaporation of water. A change in density has also been noted by Spring,[e] who found that the amount of water required to fill the spaces of a given mass of sand was greater than would be expected if it were merely a phenomenon of occupying the air spaces. This phenomenon has been ascribed to an increase in the density of the water at the surface.

TEMPERATURE INCREASE CAUSED BY MOISTENING SOILS.

Stellwaag[f] found the following increases in temperature by moistening soils and soil constituents with water: 8.33° C. for a calcium carbonate sand rich in humus; 6.6° C. for ferric hydroxide; 5.57° C. for a loam soil.

HEAT EVOLVED ON WETTING QUARTZ POWDER.

Martini[g] gives 13.73 calories as the heat evolved on wetting 1 gram of quartz powder with water. A mechanical analysis of the powder is not given. Similarly, charcoal evolved 14.45 calories per gram when placed in water. Ercolini[h] finds slightly different values: 13.23 calories for quartz, and 14.23 calories for charcoal.

HEAT EVOLVED ON WETTING CHARCOAL WITH VARIOUS LIQUIDS.

Martini[i] found each liquid has its own heat of wetting. Thus with granulated animal charcoal at 17°–18° C. water showed a rise in temperature of 15.58°; absolute ethyl alcohol, 17.47°; ethyl ether,

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[a] Wied. Ann., **29**, 114 (1886).

[b] Bihang. till K. sv. Vet.-Akad., Handl. 24, Afd. II, No. 5 (1898).

[c] Minchin, Hydrostatics and Elementary Hydrokinetics, 311 (1892).

[d] Phil. Mag., (5) **30**, 473 (1890).

[e] Mem. Soc. Geol. Belge, **17**, 13 (1903).

[f] Forsch. Geb. Agr. Phys., **5**, 211 (1882).

[g] Atti del R. Istituto Veneto (7) **9**, 958 (1897).

[h] Nuovo Cimento (4) **9**, 110 (1899).

[i] Atti del R. Istituto Veneto (7) **8**, 510 (1896).

17.50°; ethyl acetate, 18.94°; benzene, 17.60°; carbon disulphide, 20.60°. It is interesting to note, too, that benzene with impure charcoal gave no rise in temperature, and that amyl alcohol showed this same indifferent action, evolving no heat. Absolute alcohol caused a rise of 5.55° only, whereas less pure alcohol showed 10.03° rise. Unfortunately, data are not available for the conversion of these observations to calories.

Linebarger,[a] using the same sample of quartz powder with which Martini worked, found 13.80 calories evolved per gram when placed in water; 11.21 and 10.88 calories for nitrobenzene; 9.61 and 7.55 calories for toluene; 4.09 calories for benzene; 11.84 and 12.46 calories for pyridine. The granules of this powder had an average diameter of 0.0005 cm. Using another sample, with average diameter of grain, 0.00096, Linebarger found that practically half the quantity of heat given above for each liquid was evolved on wetting. He found, in common with previous investigators, that the relative quantity of liquid does not influence the heat effect. A certain minimum quantity of liquid is necessary to produce the maximum heat change, but any excess of that amount has no perceptible influence. The heat effect per unit mass of the powder is the same for the same liquid at the same temperature, provided this minimum amount be present.

HEAT EVOLVED BY POWDERS ON ABSORBING WATER VAPOR.

The experiments of Parks[b] indicate that the heat which water vapor liberates when it condenses upon the surface of the silica grains is returned to the liquid water (which is in the vessel with the silica to maintain the air space saturated with water vapor) as it evaporates to take the place of the water vapor which the silica had adsorbed. In the end, therefore, the same quantity of water is adsorbed and the same quantity of heat liberated when the silica is in contact with water vapor as when it is placed under liquid water.

PARKS'S LAW.

In another paper[c] Parks formulates a law, "When silica, sand, or glass is brought in contact with water, at approximately constant temperature, the heat evolved is proportional to the area of the surface exposed by the solid, and the amount of heat developed per square centimeter is approximately 0.00105 calorie when the temperature is near 7° C." And for a range of 17°, from 7° C. to 24.3° C., this heat evolution increases 0.0000035 calorie per square centimeter of surface for each degree increase in temperature. It has been suggested that this law of Parks's may be used to ascertain the area of a powder or a soil per gram by determining experimentally the heat evolved when the powder is placed in water and dividing this quantity of heat by the calories which 1 square centimeter of surface liberates when wetted. But here again we meet the same difficulty which confronted Kayser[a] in his attempt to determine the area of the surface presented by the grains of powder by measuring the quantity of water adsorbed by the powder and then dividing this weight of water by the number of grams of water adsorbed upon a surface of standard material. He failed to find a standard material. Each surface tried showed a different degree of adsorption. The researches quoted above show that each soil constitutent has its own heat effect when moistened; consequently, an attempt to measure the area of a soil in this manner is not promising.

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[a] Phys. Rev., **18**, 48 (1901).

[b] Phil. Mag. (6), **5**, 521 (1903).

[c] Phil. Mag. (6), **4**, 247 (1902).

In Linebarger's experiments[b] the heat evolved compared to the surface of silica exposed is greater than that shown by Parks. But in considering this apparent clash of results one must bear in mind that Linebarger has measured the heat effect of the same solid in different liquids and finds the ratio of the different heat effects for coarse and fine powder the same in different solvents. This is very strong evidence, indeed, that the heat evolved is proportional to the surface. The error involved in calculating the effective area of a powder is enormous. Parks's values involve the area as calculated from microscopic measurement of the granules. Linebarger's ratio is absolute, since he takes merely average samples of each grade of powder, without attempting to evaluate the area, and uses these two samples with each liquid.

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[a] Wied. Ann., **24**, 450 (1885).

[b] Phys. Rev., **18**, 48 (1901); see also:

Cantoni, Rend. del R. Istituto Lombardo, Class di Scienze Matematiche e Naturali, **8**, 135 (1866);
Martini, Atti del R. Istituto Veneto, (7) 8, 502 (1896); (7) **9**, 727 (1897); (8) **2**, 615 (1900);
Tait, Proc. Roy. Soc. Edinb., **11**, 51 (1880–81); **11**, 813 (1881–82);
Marshall Smith and Omond, Ibid. **11**, 626 (1881–82);
Amagat, Compt. rend., **116**, 946 (1893);
Lussana, Nuovo Cimento (4) ii, 233 (1895);
Lagergren, Köngl. Vet. Akad. B. **24**, Afd. ii, Stockholm, (1899);
Tate, Phil. Mag. (4) **20**, 508 (1860);
Melsens, Mem. Acad. Belg., **28**, (1873); Ann. Chim. Phys. (5), **8**, 622 (1874);
Chappuis, Wied. Ann., **19**, 21 (1883);
Wiedemann and Lüdeking, Wied. Ann., **25**, 145 (1885);
Gore, Phil. Mag., **37**, 306 (1894); Birm. Phil. Soc. Proc., **9**, part 1, (1893),
Ercolini, Nuovo Cimento (4) **9**, 110 (1899);
Bellati, Atti del R. Istituto Veneto (8) **2**, 931 (1900);
Fitzgerald, Nature, **49**, 293, 316 (1894);
Weber, Pogg. Ann. 154, 367 (1875);
Barus, Phil. Mag. (6), **4**, 24, 262 (1902);
Magnus, Phil. Mag. (4), **6**, 336 (1853).

HEAT EVOLVED BY SWELLING STARCH.

Rodewald[a] has studied quantitatively the energy changes of starch as it absorbs water. One specimen evolved 24.02 calories per gram of starch; another, 19.4 calories. He finds that the greatest available effect in the passage of heat into work which can be reached in the swelling of starch is 11.4 per cent of the total heat effect, which latter is 24.02 calories. This result is based upon measurements of volume change during swelling. The average pressure between the ultramicroscopic cells of starch is calculated as 2,137 atmospheres, while very near to a cell wall the pressure would be much greater. Comparing this value with those of Dupré (25,000 atmospheres) and Young (23,000 atmospheres) and Lagergren (6,000 atmospheres), it seems probable that in the swelling of starch the imbibition effect predominates over the absorption.

COMPENSATING FACTORS THAT MASK THE ENERGY CHANGE IN ABSORPTION OF MATERIAL FROM SOLUTION.

The foregoing citations contain only the heat changes consequent upon the wetting of powders and the absorption of vapors. No values for the energy change accompanying absorption from solution are available, although it is possible to make such measurements. This phenomenon is analogous to the general problem of the energy changes attendant upon the process of solution. In this case the determinations of the individual forces at work is difficult; the actual heat and volume changes measured are the resultant of all the forces involved. Among these are the attraction of solvent and solute and the cohesion of the solute. Some idea of the cohesion of the solute may be obtained from its heat of vaporization. In like manner it is difficult to estimate the individual forces in the case of absorption from solutions, for there are the added factors of the attractions of the absorbent for both solvent and solute. At present the best indication of the magnitude of these forces is the chemical decomposition which they produce—decompositions which, effected in other ways, require large quantities of energy.

THE CONDITION OF THE ABSORBED SUBSTANCE.

THEORIES PROPOSED.

The earlier theories of absorption, and more especially of adsorption, were based either upon the assumption of a pressure at a surface layer of liquid higher than that in the free liquid or upon the theory of wetting of a solid by a liquid.

Only at the saturation point is it possible to consider the effect of pressure upon the solubility. The case of absorption from unsaturated solution must be considered as a distribution of the solute between layers of the liquid at different densities. This is analogous to the distribution of a solute between two different liquids or to the Soret effect, obtained when different portions of the solution are maintained at different temperatures, resulting in two solutions of different concentrations. The effect of pressures has been discussed by various authors.[a]

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[a] "Researches on the Swelling of Starch," Lipsius and Fischer, Leipsig, 1896.

From the principle of Le Chatelier [b] it follows that if on solution contraction occurs there will be a positive adsorption, i. e., the surface layers will become more concentrated.

A theory of absorption from solution has been based upon considerations of the surface tension between solid and liquid,[c] which tension there is no direct method of determining experimentally. It has, however, been derived from the theory of wetting of a solid by a liquid, and is shown to be less than the surface tension between solid and gas. In case the surface tension between solid and liquid is lowered by the addition of a substance soluble in the liquid, it follows that there will be adsorption of the substance on the surface of the solid, for the potential surface energy will tend to become lower by further concentration at the bounding surface.

PHYSICAL ABSORPTION.

Without entering deeply into the distinction between chemical and physical change, we may for practical purposes define a physical change as one in which the altered substance retains sufficient of its former characteristics to be recognizable as the same material present before the change took place.

On the basis of this definition we may classify a number of absorption reactions as physical changes, in that the dissolved substance as a whole is concentrated in the layer of liquid close to the absorbing solid, and in some cases even deposited upon its surface in a condition nearly or quite solid.[d] A good example of this is the adsorption of the organic dye gentian violet (gentianin) by quartz powder. Here the dye is retained in a thick layer upon the grains of quartz while the solution bathing the quartz is a thousand to ten thousand parts per million below its saturation point for this dye. Under the microscope the dye upon the quartz grains shows its characteristic colors for reflected and transmitted light, and when the dyed powder is subjected to percolation with distilled water the dye is gradually removed and recovered intact.[a]

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[a] Thomson, Applications of Dynamics to Physics and Chemistry, p. 237-240; Freundlich, Zeit. phys. Chem., **57**, 422 (1906); see also Lagergren, Bihang t. k. Sv. Vet. Akad. Handl., **24**, 2, No. 4 and 5 (1899); Parks, Phil. Mag (6) **4**, 240 (1902); (6) **5**, 517 (1903).

[b] See Bancroft, Phase Rule, p. 4 (1897).

[c] For references, see Freundlich, Zeit. phys. Chem., **57**, 421 (1906).

[d] Thomson, Applications of Dynamics to Physics and Chemistry, 1888, p. 91; Freundlich, Zeit. phys. Chem., **57**, 385 (1906); Ostwald, Lehrbuch der Allgemeine Chemie, (1891), p. 1096; Frank K. Cameron and James M. Bell, Bul. No. 30, Bureau of Soils, U. S. Dept. Agr. 1905.

In some cases the adsorbed material is retained in solution in the layer of liquid close to the surface of the solid. This is very well shown for alkaline carbonate solution with soil. The fine clay particles when suspended in the solution produce no appreciable lowering of the electrical conductivity, but when they are removed by centrifiugal action or by settling the quantity of adsorbed material which they carry down with them is sufficient to reduce the conductivity of the supernatant liquid to a marked degree.[b] And since these carbonates, or any chemical compounds they might form, have a low conductivity as solids it follows that they are present in solution at the surface of the soil particles and contribute to the conductivity of the main body of liquid in which the soil is suspended. Should the clay contain hydrated silica, alumina, or ferric oxide in an amorphous condition, part of the solution will be imbibed by them and removed when the suspension is cleared by settling; but in this case, too, the fact that the absorbed material contributes to the electrical conductivity shows that it is still in solution.

ABSORPTION BY CHEMICAL FIXATION.

In addition to these three types of physical absorption, we may have chemical fixation of dissolved bodies at the surface of a solid. The solute may be removed from solution as a whole and added to the solid absorbent to form a compound. Thus metallic silver will absorb chlorine from solution forming silver chloride. The absorbing solid, too, may lose some constituent at the same time that it absorbs the solute. Solid calcium hydroxide absorbs carbon dioxide from solution and loses water. Much more complicated replacement reactions between soil constituents and soil solution take place, as set forth at length in a previous bulletin.[c]

Since many cases of absorption are known in which both physical and chemical changes occur, the above classification, although convenient, should not be rigidly applied. Indeed, all gradations of union are possible, from purely physical surface adhesion—which still depends upon the composition of the bodies involved—to purely chemical combinations. One important intermediate step may be solution, either liquid or solid.

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[a] Trans. Am. Electrochem. Soc., **10**, 67 (1906).

[b] Electrochem. and Met. Ind. **5**, 257 (1907).

[c] Bul. No. 30, Bureau of Soils, U. S. Dept. Agr., 1905.

CALCULATION OF THE PROBABLE THICKNESS OF ADSORBED MATERIAL.

A series of calculations for several soils is presented in Table X. The concentration of gentian violet dye solution at the surface of soil grains is estimated from the quantity of hygroscopic water and from the quantity of dye absorbed by the soil. This involves the assumption that the hygroscopic water determined by allowing dried soil (110° C.) to take up moisture from a saturated atmosphere is the same in quantity as the moisture retained upon the soil grains when the soil is in a saturated condition.[a] The results not only show the magnitude of the surface concentration, but also are of value in studying the physical condition of soils.

TABLE X.—*Relation of gentian violet dye absorbed to area of soil and to hygroscopic water.*

Soil.	Dye absorbed per 100 grams soil.	Hygroscopic water per 100 grams soil.	Dye in solution on soil grains.	Volume of solution retained by 100 grams of soil.	Area of soil per gram.
	Grams.	*Grams.*	*Per cent.*	*C. c.*	*Sq. cm.*
Marshall silt loam	0.3	4.0	7.0	....	2,320
	.485	4.0	10.8	47	....
	.9999	4.0	20.0	50	....
	1.50	4.0	27.3	47	....
	1.999	4.0	33.3	....	....
	2.497	4.0	38.4	....	....
	2.991	4.0	42.8	....	....
	3.119	4.0	43.8	....	....
	3.70	4.0	48.1	....	....
Hagerstown loam	.0	4.5	....	61	....
	.20	4.5	4.3	56	2,270
	.4	4.5	8.2	54	....
	.5	4.5	10.0	55	....
	.998	4.5	18.1	57	....
	1.495	4.5	25.0	50	....
	1.981	4.5	30.6	45	....
	2.045	4.5	31.3	....	....
	2.025	4.5	31.0	....	....
Quartz flour	.000	.8	....	36.5	1,260
	.019	.8	2.32	36	....
	.038	.8	4.53	38	....
	.075	.8	8.58	48	....
	.098	.8	10.90	50	....
	.190	.8	19.20	46	....
	.265	.8	25.0	40	....
	.289	.8	26.52	37	....
	.295	.8	26.93	34	....
	.297	.8	27.03	30	....
	.293	.8	26.80	29	....

Gentian violet is not very soluble in water, a 2 per cent solution being viscous and 6.81 per cent its solubility at 25° C.; yet the calculated per cent of dye in solution on the soil grains is 48.1 for Marshall silt loam, 31 for Hagerstown loam, and 27 for quartz flour. Although the hygroscopic moisture held by the quartz is less than one-fifth of that of the Hagerstown loam, the percentages are in very close agreement. The percentage of dye held in solution is actually higher than these values given, since the dye absorbed is in or on the soil grains, while part of the hygroscopic water should be reckoned as capillary water and is the same in concentration as the supernatant solution fróm which the dyed soil grains have settled out.

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[a] Parks, Phil. Mag. (6), 5, 521 (1903).

Since the calculation just made gives such high values for the concentration of dye upon the soil grains, it may even be that the dye is not in solution in the surface layer, but has separated upon the grains as a solid. The work of Rohde[a] is in line with this. He states that the aqueous solutions of fuchsine and methyl violet form at their surfaces solid layers which through their metallic luster are unmistakably evident to the eye. The surface of the liquid becomes first more concentrated, then viscous, and finally stiff and solid, so that in the condition of equilibrium the solution is covered with a skin of solid dyestuff.[b]

Rohde says, again, that the solid surface layer is the thicker and forms the faster the more concentrated the solution. According to his calculations the thickness of the layer (of solid dye) is always of a lower order of magnitude than the radius of the sphere of action. The present calculation, however, shows that the layer of dye on the grains of quartz flour, Marshall silt loam, and Hagerstown loam is many fold that of the calculated molecular dimensions. This is also true for the absorbed layer of eosin and for manure extract, and aside from these calculations microscopic examination shows a very appreciable layer of dye on the grains.

EFFECT OF ABSORPTION UPON THE PHYSICAL CONDITION OF THE SOIL.

RELATION OF ABSORPTION TO THE FORMATION OF AGGREGATES.

The absorption of nutrient salts by the soil not only maintains a proper soil solution, but also exercises a marked influence upon the size of the soil aggregates. This soil structure in turn governs the water-holding power, the porosity, and consequently the aeration of the soil; and these factors are of the utmost importance to the bacterial life in the soil, as well as to the changes in the organic and mineral constituents. The effect of absorption upon the soil solution has been discussed in several preceding chapters.

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[a] Ann. Phys., 19, 935 (1906); see also the references given in the preceding sections.

[b] "Es spricht nichts gegen die Annahme, dass die molekularen Kräfte, welche die Ausscheidung des festen Farbstoffs bewirken, dieselben sind, wie bei der Oberflächenspannung der Flüssigkeiten tätigen. Es Würden namlich die grossen zwischen zwei Wasser molekülnwirkenden Kräfte, welche auch die grosse Oberflächenspannung des Wassers zur Folge haben, es bewirken müssen, dass die an der Oberfläche der Farbstoffslösungen befindlichen Farbstoffmoleküle, mit frosserer Kraft in das innere der Lösung gezogen werden, als die dort befindlichen Farbstoffmoleküle, was die bobachtete Anreicherung der Oberfläche an Farbstoff zur unmittelbaren Folge ergibt."

The present chapter has to do with the changes in the physical structure of the soil attendant upon the addition of various soluble substances, such as fertilizers and correctives and salt water from inundations. When a salt is absorbed by a soil in suspension, there may occur either the formation of larger aggregates or else the breaking up of aggregates already present. Larger aggregates settle more readily and occupy a larger volume, while the smaller aggregates or single grains settle much more slowly and into a compact bed.

The direct relationship between the absorption of soluble material by percolates in suspension and their settling has been shown by Linder and Picton,[a] as well as by Whitney and Ober.[b] Colloids which settle from suspension in neutral solution carry down small quantities of metallic hydroxides.

Several hypotheses have been advanced to account for the formation and breaking up of aggregates.

Many of the agents which produce flocculation have been found to be more or less hydrolyzed in aqueous solution, and the flocculating power has been attributed to this hydrolysis. Freundlich[c], however, has found that the flocculating power of barium salts, which are scarcely hydrolyzed, is almost equivalent to that of beryllium salts and uranyl nitrate, both of which are strongly hydrolyzed, and as all of these salts have bivalent cations this can not be attributed satisfactorily to the difference in valence.

Another theory growing out of their work attributes the precipitation of suspended particles to the ions of the salt in solution. The mechanism of this precipitation is such as to constitute the neutralization of the charge of electricity upon the suspended particles by the ions carrying the opposite charge. On the basis of their experiment, in which they used electrolytes and nonelectrolytes, it has been claimed by Barus,[d] Bodländer,[e] Freundlich,[f] and Whitney and Ober[g] that the power to flocculate colloids is possessed exclusively by electrolytes.[h]

The flocculation of colloids by electrolytes has been investigated by Schulze,[i] Hardy,[j] and many others, and there has been a tendency to correlate the flocculating power of an ion with its valence. Schulze found that the power of salts of univalent, bivalent, and trivalent metals to flocculate colloids was in the proportion of 1 to 30 to 1,650. This in turn has been ascribed by Bredig[a] and Spring[b] to the hydrolysis of the salt, the degree of which increases very rapidly as the valence of the cation increases.

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[a] Jour. Chem. Soc., **67**, 63 (1895).

[b] Jour. Am. Chem. Soc., **23**, 842 (1901); Zeit. phys. Chem., **33**, 385 (1901).

[c] Zeit. phys. Chem., **44**, 129 (1903).

[d] Am. Jour. Sci., **37**, 122 (1889).

[e] Nach. K. Ges. Wiss., Göttingen, 1893, p. 267.

[f] Zeit. phys. Chem., **44**, 136 (1903).

[g] Jour. Am. Chem. Soc., **23**, 842 (1901); Zeit. phys. Chem., **33**, 385 (1901).

[h] Compare, Kahlenberg, Jour. Phys. Chem. **6**, 1 (1902); **10**, 593 (1906).

[i] Jour. prakt. Chem. **133**, 431 (1882); **135**, 320 (1883).

[j] Proc. Roy. Soc., **66**, 111 (1900); Zeit. phys. Chem., **33**, 385 (1901).

Colloid suspensions have been divided into two classes: Those which migrate toward the cathode under electrical stress and those which migrate toward the anode. The colloids which migrate toward the anode are said to be precipitated by anions, and vice versa. This migration of the colloids resembles the behavior of an electrolyte, and the theory has been advanced that colloids in solution are in reality large aggregations with small electrical charges,[c] which are counterbalanced by the presence of ions carrying the opposite charge. Thus there would be an equilibrium between the two, and a disturbance of the equilibrium by the addition of a salt to the solution tends to precipitate the colloid. Further, both classes of colloidal suspensions have the peculiarity that any one is precipitated from the solution when added to a suspension of one of the other classes, the precipitate being of course a mixture of the two.[d]

Hilgard[e] has shown that increase of temperature decreases flocculation; alcohol and ether decrease flocculation, as do also alkalies, while neutral salts, acid, and lime promote flocculation. Whitney[f] has also given considerable attention to flocculation, especially its effect upon the adaptation of special crops to soils. At his suggestion Bliss[g] made a study of the precipitation of suspensions and found that sodium chloride and hydrochloric acid induced flocculation, while potash and ammonia inhibited it, and also that the concentration of the solution is a determining factor. Bodländer[h] has given the concentration of typical acids, bases, and salts required to precipitate kaolin suspended in water. Sachsse and Becker[i] have determined the percentage of several salts precipitated from suspension by lime water.

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[a] Anorganische Fermente, 1901, p. 15.

[b] Bul. Acad. Roy. Belg., 1900, 483.

[c] Duclaux, (Compt. rend., **140**, 1544 (1905)) considers the granules of a colloidal solution as of such magnitude that they may be regarded as conductors of electricity.

[d] Linder and Picton, Jour. Chem. Soc., **67**, 63 (1895); Freundlich, Zeit. phys. Chem., **44**, 129 (1903); des Bancels, Compt. rend., **140**, 1647 (1905).

[e] Forsch. Geb. Agr. Phys., **2**, 441 (1879); also Silliman's Jour., **17**, March, 1879; ibid, **6**, Oct. and Nov., 1873: See also S. W. Johnson, Rept. Conn. State Board Agr., 1877-1878, Hartford, 1878, The reasons for Tillage.

[f] Bul. No. 5, Division of Agricultural soils, U. S. Dept. Agr., 1896, p. 9; Fourth Annual Report, Maryland Exp. Sta., 1891, p. 258; Bul. No. 4, Weather Bureau, U. S. Dept. Agr. (1892), p. 80; See also Wiley, Principles and Practices of Agricultural Analysis I, 1894, p. 171.

[g] Phys. Rev., **2**, 241 (1895).

[h] Neues Jahrb. f. Mineral. II, p. 147, 1893; abstr., Forsch. Geb. Agr. Phys., **18**, 76 (1895).

[i] Landw. Vers.-Stat., **45**, 137 (1894); abstr., Forsch. Geb. Agr. Phys., **18**, 78 (1895).

Matthews[a] has suggested that the precipitation of colloids by electrolytes is brought about by an alteration in the surface energy of the colloid. The suspending power of the solvent has been correlated with its dielectric constant. Buckingham,[b] however, has shown experimentally that this suspending power, while parallel with the dielectric constant, shows variations of a totally different order of magnitude. Many cases are known in which the flocculation and suspension of particles, bacteria, etc., alternate as the concentration of the solute is increased.[c] This recurrence of flocculation and suspension[d] puts in doubt the hypothesis that suspended particles settle because their charges are neutralized by the ions about them. Buxton and Shaffer[e] have suggested that this precipitation may be analogous to the phenomenon of "salting out," in which a new distribution of the components between solid and liquid phases in the colloidal suspension takes place. In other papers Teague and Buxton[f] have investigated the migration of suspended particles under the influence of electrical stress and found that the direction in which the suspension migrates depends upon the concentration of the electrolyte, and, indeed, alternates as the suspension or flocculation alternates. They suggest the possibility that this alternation may be due to a decrease in the absorptive power of the suspended particles in more concentrated solutions.

Hilgard has given considerable attention to the subject of sedimentation, especially in his method for the mechanical analysis of soils. He has also studied the effect of different salts, alkalies, and acids upon the physical structure of the soil, recognizing the effect of these agents upon sedimentation. His latest statement concerning the formation of soil crumbs is of interest: "When land is plowed in the proper moisture condition, the crumbs or floccules are held together by the surface tension of the capillary films (menisci) of water at the points of contact. In the case of sands, the crumbs will collapse into single grains whenever the water films evaporate, unless some cementing substance was dissolved or suspended in the water. Lime carbonate is one of the substances most commonly found permanently cementing the floccules; hence the ready tillage of most calcareous soils, and especially the loose texture of the 'loess' of the western United States and of Europe and Asia. In these deposits we find sandy and silt aggregates or concretions ranging from 10 or more inches in length (loess puppets) to microscopic size, held together by lime carbonate, but collapsing into silt and sand when the material is treated with acid so as to dissolve the cement. The rough surface of these aggregates, gripping into each other, explains the stability of the steep loess cliffs in the United States, as well as in northeastern China, as observed by Von Richtofen and Pumpelly." [a]

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[a] Am. Jour. Physiol., **14**, 203 (1905).

[b] Trans. Am. Elec.-Chem. Soc., **9**, 261 (1906).

[c] Bechhold, Zeit. phys. Chem., **48**, 385 (1904).

[d] With regard to the protecting action of gelatine and other substances upon the colloidal suspensions, reference may be made to Bredig, Anorganische Fermente (1901).

[e] Zeit. phys. Chem., **57**, 47 (1906).

[f] Ibid., **57**, 64, 76 (1906); **60**, 469, 489 (1907); **62**, 287 (1908).

Mayer,[b] starting from the well-known settling of muddy water by addition of common salt, divides the salt solutions into two classes: (1) those which behave like distilled water, allowing the soil particles to settle regularly according to their diameters and specific gravities; (2) those solutions in which the precipitate forms a mass of cohering flocs, the neighboring particles showing a tendency to hold together. He places hydrochloric acid, nitric acid, sulphuric acid, their salts, fixed alkalies (NaOH, KOH, LiOH), and ammonia in the first class. Alkali sulphates have only a slight tendency to promote sedimentation. Lime water precipitates the suspension of soil even better than fixed alkalies, while powdered calcium carbonate mixed with the soil before stirring with water has no effect upon the rate of settling.

Mayer also showed that sedimentation is not perceptibly affected until the concentration of solution added reaches a fairly definite per cent. The percentages at which precipitation just takes place are for the following solutes: Soap, 2.5; ammonia, 2.5; neutral sodium phosphate, 2.0; phosphoric acid, 0.8; potassium hydroxide, 0.56; sodium sulphate, 0.4; calcium hydroxide, 0.08; sulphuric acid, 0.025. The soil used was a fine clay from Iowa washed free of carbonates by hydrochloric acid. He showed that a soil subjected to percolation by distilled water at constant pressure allows the liquid to pass through at a constantly decreasing rate. This decrease is produced by packing and by clay particles lodging in the minute soil channels. When a salt solution belonging to his second class—i. e., one capable of precipitating the soil from suspension in water—is passed through a soil already washed and well packed down by percolation, an increase in the rate of flow is observed. He confirmed this phenomenon for sodium chloride and calcium hydroxide and, furthermore, showed that on washing out by percolation the salt absorbed by the soil during its contact with salt solution the rate of flow was very greatly reduced. This phenomenon has been fully confirmed in this laboratory[c] for potassium carbonate solutions passing through Galveston clay, Marshall silt loam, Hagerstown loam, and

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[a] Hilgard, Soils, p. 110 (1906).

[b] Forsch. Geb. Agr. Phys., **2**, 251 (1879).

[c] See page 94; also Cameron and Patten, Jour. Am. Chem. Soc., **28**, 1645 (1906); also Hissink, Chem. Weekblad. **4**, 663 (1907).

Norfolk sand. As a practical application of this sedimentation effect produced by salts, Mayer suggests first that lands flooded by sea water may suffer a deterioration in their physical condition on being again drained. This close packing of the soil would be likely to appear in the second year after flooding rather than in the first. He thinks, too, that the packing of the soil and consequent reduction of air space and ventilation facilitates the reduction of iron sulphate to hydrogen sulphide, or its analogues, especially in alkali soils. As land flooded by sea water, and thus put into dense condition, was not improved by use of lime, he suggests as a last resort that the land be left fallow, subject to freezing and thawing and to the action of turned-under green manure, such as natural plant growth. He points out most strongly the injury to the mechanical structure of a soil rich in clay produced by repeated fertilizing with potassium nitrate. A soil forced in this manner at first gives fine crops, then shows a sudden drop, which can not be corrected by simple addition of all the standard fertilizers. The soil is ruined mechanically for a long time. One of the reasons for this is that the nitrates, like the chlorides, are comparatively easily washed from the soil, and the salt being removed the soil grains pack down in a single-grain condition very hard to overcome. Swaving[a] likewise found that soils flooded by sea water were greatly injured in their physical condition, although not enough salt was absorbed to injure plants.

Fickendey[b] states that the precipitation of a suspension of a natural clay soil requires a much higher concentration of alkalies than is necessary to flocculate a kaolin suspension. He explains this as due to the protective action exercised upon the soil particles by the humic acids which go into the solution when the soil is treated with alkalies and alkali carbonates. Artificial humic acids can likewise restrain precipitation, though less strongly than the humus products of the soil. Tannin also prevents sedimentation, while starch has no perceptible effect. Pure gelatine without addition of electrolyte exerts a precipitating effect upon kaolin suspensions, which increases with the gelatine concentration up to a maximum and then drops considerably. Addition of alkalies to the gelatine solution displaces this maximum speed of settling toward the side of low gelatine concentration; but in acid solution this maximum appears nearer the region of concentrated gelatine solutions and is sharply defined. These observations are taken as giving new light upon the manurial efficiency of lime, in that it precipitates the humic acids of the soil, thus removing substances which tend to maintain the soil in a single grain condition, and enables the soil grains to flocculate and assume open physical condition.

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[a] Landw. Vers.-Stat., **51**, 463 (1898-99).

[b] Jour. Landw., **54**, 343 (1906).

EFFECT OF ABSORPTION UPON WATER-HOLDING POWER OF SOILS.

Van Bemmelen[a] and others have set forth the relation between the absorptive power of a finely divided solid and the quantity of water retained by the individual particles within their own bodies. But in addition to this imbibition effect, soluble material held in concentrated form upon the surface of powder grains materially alters the quantity of solution which this powder can retain in the space between grains after settling from suspension in the given solution.

Wollny[b] has shown that from every standpoint the single grain soil is inferior to a flocculated soil as regards its moisture content and conservation, as well as in respect to aeration.

Ulreich[c] gives data on the influence of various hydroxides, carbonates, phosphates, sulphates, nitrates, and chlorides upon the water content of soils. He concludes from his data that the different hydroxides and salts, in a considerable degree, but in different direction, exercise an influence upon the water-retaining power of the soil. According to their action they may be brought into three groups, of which the first comprises those compounds which produce a lowering of the water capacity of the soil, i. e., hydroxides and carbonates of the alkalies as well as phosphates. A second group includes those salts which appear to be almost without influence upon the retention of water; these are the sulphates. In a third class are the compounds such as nitrates, chlorides, and calcium hydroxide, which increase the water capacity of the soil. He also compares the effect of Knop's nutrient solution[d] with that of lime and obtains similar results with all the soils tried. The Knop solution increased the water capacity of the soil, as would be expected from the preponderance of nitrates and chlorides. This effect is greater as the concentration of the solution increases, so far as his experimental data go, save in the case of gypsum, where the soil held the same volume of solution at 0.1 per cent $CaSO_4$ as at 0.5 per cent, and showed a very slight decrease in water content when a 1 per cent solution was used.

The interdependence of absorption, flocculation, and physical condition of soils is shown in a series of preliminary experiments carried out by Mr. J. O. Belz. The quantity of solute retained in the soil spaces after settling from a given solution was determined by measuring the height of the soil surface. Since the true volume of the soil grains is a constant, the volume of water held in the capillary spaces may be calculated from this height. Susquehanna clay appears to retain a maximum volume of liquid in potassium hydroxide solution when the concentration is near 0.01 N. This same soil retains more of 0.1 N ammonia solution than of other concentrations used. In both these cases the definite location of the concentration giving maximum open structure remains to be determined, but its existence is assured. With sulphuric acid the volume of solution in the pore spaces is greater as the concentration of acid in solution increases up to 0.1 N, the strongest solution used. Susquehanna clay and quartz flour retain less of distilled water in their capillary spaces than of solution, while Hagerstown loam holds more of distilled water—which, of course, becomes a soil solution proper to that soil—than of dye solution; yet this soil, too, shows a maximum after the first quantities of dye have been absorbed. Calcium nitrate solution (200 c. c.) was shaken up with 25 grams of Sharkey clay and allowed to settle three days before taking the reading. The clay retained a greater volume of the 0.01 N solution than of the other solutions higher and lower in concentration.

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[a] Zeit. anorg. Chem., **23**, 112 (1900).

[b] Forsch. Geb. Agr. Phys., **16**, 406 (1893); **18**, 63 (1895); Puchner, Ibid., **19**, 1 (1896).

[c] Ibid., **19**, 52 (1896).

[d] This solution contains KH_2PO_4, $MgSO_4$, KNO_3, NH_4Cl, in equal parts by weight, with 4 parts $Ca(NO_3)_2$.

Table XI gives the results of a number of experiments also carried out by Mr. Belz. The solutions used were 0.5 and 0.1 normal, except lime, where the concentration was calculated on a basis of pounds per acre. Fifty grams of Susquehanna clay were shaken up with 150 c. c. of solution and allowed seven days in which to come to equilibrium. The results show that the solute used, and in particular its concentration in the soil and in the solution, determines the volume of solution which the soil can retain in its capillary spaces. It is to be remembered that the original concentrations given in Table XI have changed, since in each case the soil has abstracted a goodly quantity of solute from the solution.

TABLE XI.—*Volume of solution retained by Susquehanna clay on settling from various solutions.*

[50 grs. soil+150 c. c. solution.]

Solute.	(1) Volume of solution in soil.[a]	(2) Volume of solution in soil.	(1) Difference in volume over distilled water check.	(2) Difference in volume over distilled water check.
	0.5 normal solution.	0.1 normal solution.		
	C. c.	*C. c.*	*C. c.*	*C. c.*
Distilled water	75.4	....	....	....
Lime (1)	72.0	....	−3.4	....
Lime (2)	50.1	....	−16.3	....
$(NH_4)_2CO_3$	104.6	105.6	29.2	30.2
K_2CO_3	91.4	126.4	16.0	51.0
Na_2CO_3	128.1	131.9	53.2	66.5
H_2SO_4	120.9	101.2	45.5	25.8
K_2SO_4	110.4	117.7	35.0	42.3
Na_2SO_4	126.1	113.8	50.7	38.4
$(NH_4)_2SO_4$	111.3	117.6	35.9	42.2
Na_2HPO_4	126.7	128.7	51.3	53.3
$(NH_4)_2HPO_4$	118.1	125.8	42.7	50.4
K_2HPO_4	108.7	123.2	33.3	47.8
$Ca(NO_3)_2$	60.5	69.4	−14.9	−6.0
$NaNO_3$	97.7	69.8	22.3	−5.6
KNO_3	80.4	70.1	5.0	−5.3
$(NH_4)NO_3$	73.0	89.4	7.6	14.0

[a] The volume of the air-dry soil is 41.1 c. c. for 50 grams.

Column 1=1,000 pounds per acre. Column 2=500 pounds per acre.

Increase in lime increases the volume of solution in the soil, and the same is true for sodium, potassium, and ammonium nitrates, sulphuric acid, and sodium sulphate; but the other salts studied show the reverse, the volume of solution retained by the soil being greater for lower concentrations. This apparent lack of agreement of the effect of various solutes is due to the fact that each solution has its own particular concentration for which the soil in contact with it will assume a maximum open structure.

The following experiments were undertaken to establish a relationship between the quantity of substance absorbed by the particles and the volume of solution which they can retain in the spaces between particles when the aggregate of grains is allowed to settle out of solution and pack down. Consequently in addition to determining the concentration of the solution remaining above the quartz flour, as shown in Table IV, its volume was measured; that is, the volume of liquid which could be drained off from the quartz after the bottles containing the system had been centrifuged at high speed for about ten hours and then allowed to stand some six weeks upon the shelf. As the quartz had settled into a compact mass in every bottle, the volume of liquid remaining above the quartz could be poured off cleanly and measured to within less than 0.3 c. c. The water added to each sample of quartz may be considered to be in three conditions—absorbed water, that held in the capillary spaces, and free water. The free water was directly determined, and the absorbed water has been determined for the same samples of quartz;[a] consequently the water held in the capillary spaces may be estimated by difference.

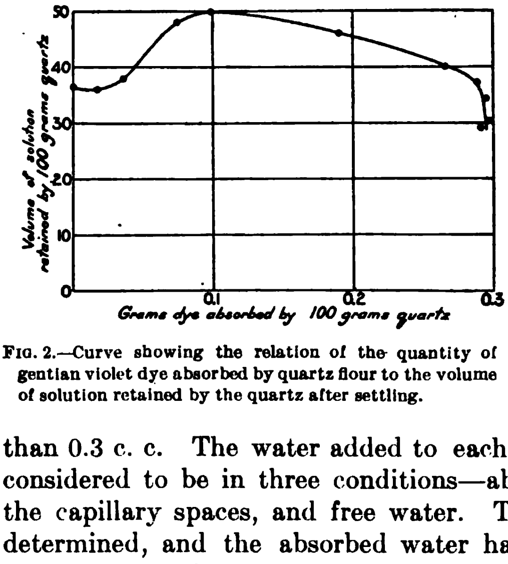

FIG. 2.—Curve showing the relation of the quantity of gentian violet dye absorbed by quartz flour to the volume of solution retained by the quartz after settling.

Table XII shows the volume of solution retained in the capillary spaces of 100 grams of quartz flour for different quantities of gentian violet dye absorbed by the quartz grains.[b] The corresponding concentration of each dye solution used has been given above in Table IV. The curve given in figure 2 is plotted from Table XII, using the grams of dye absorbed by 100 grams of quartz flour as abscissas and the volume of solution retained by the quartz in the capillary spaces as ordinates. The maximum of liquid is held by the quartz between its particles when about one-third of the dye which can be taken up by the grains has been adsorbed.

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[a] Patten and Gallagher, Bul. No. 51, Bureau of Soils, U. S. Dept. Agr., 1907.

[b] Trans. Am. Electrochem. Soc., **10**, 67 (1906).

Table XII.—*Volume of solution in the capillary spaces of quartz flour when various quantities of gentian violet have been absorbed.*

Dye absorbed by 100 grams of the quartz flour.	Volume of solution retained by 100 grams quartz flour.	Dye absorbed by 100 grams of the quartz flour.	Volume of solution retained by 100 grams quartz flour.	Dye absorbed by 100 grams of the quartz flour.	Volume of solution retained by 100 grams quartz flour.
Gram.	*C. c.*	*Gram.*	*C. c.*	*Gram.*	*C. c.*
0.000	36.5	0.0984	50	0.295	34
.017	36	.1901	46	.297	30
.036	38	.266	40	.293	29
.074	48	.289	37	.290	29

Similar measurements, using Hagerstown loam soil, are given in Table XIII. The maximum pore space for this soil evidently is attained with no dye present, and as the quantity of dye absorbed by the soil grains increases the soil settles together and retains less and less liquid, then expands again as it takes on more dye, till when 1 gram of dye is absorbed by 100 grams of soil, 57 c.c. of solution remains in the pore spaces. Further increase in the dye absorbed decreases the volume of solution in the capillary spaces. With 2 grams of dye to 100 grams of soil 45 c.c. of solution is held. This is 26.2 per cent less capillary liquid than the undyed soil retained, and 21 per cent less than is held by the soil containing 1 gram absorbed dye per 100 grams of soil. Marshall silt loam also shows this same volume effect, as indicated by the data in Table XIV.

Table XIII.—*Volume of solution in the capillary spaces of Hagerstown loam when various quantities of gentian violet have been absorbed.*

Dye absorbed by 100 grams soil.	Volume of solution retained by 100 grams soil.	Dye absorbed by 100 grams soil.	Volume of solution retained by 100 grams soil.
Gram.	*C. c.*	*Grams.*	*C. c.*
0.0	61	1.0	57
.20	56	1.495	50
.40	54	1.98	45
.60	55		

Table XIV.—*Volume of solution in the capillary spaces of Marshall silt loam when various quantities of gentian violet have been absorbed.*

Dye absorbed by 100 grams soil.	Volume of solution retained by 100 grams soil.	Dye absorbed by 100 grams soil.	Volume of solution retained by 100 grams soil.
Grams.	*C. c.*	*Grams.*	*C. c.*
0.50	47	3.7+	39
1.00	50	3.7+	37
1.50	47		

TABLE XV.—*Volume of solution in the capillary spaces of quartz when various quantities of eosine have been absorbed.*

Eosine absorbed by 100 grams quartz.	Volume of solution retained by 100 grams.	Eosine absorbed by 100 grams quartz.	Volume of solution retained by 100 grams.
Gram.	*C. c.*	*Gram.*	*C. c.*
0.00000	42	0.0348	29
.00135	30	.42	29

The effect of eosine dye upon the volume of solution which quartz flour can retain in its capillary space serves to further correlate flocculation and absorption with the physical condition of a soil. Considering the data given in Table XV, we see that the absorption of 0.00135 per cent of the dye reduces the volume of liquid retained from 42 c. c. to 30 c. c. and that further absorption of dye has very little effect upon the volume of liquid in the pore spaces. Turning back to Table XII and figure 2, it appears that this volume, 30 c. c., is the same as the lowest volume of liquid held by 100 grams of quartz flour when its absorption capacity for gentian violet is reached. These suspensions of quartz flour in eosine solution were allowed to settle for over five weeks, and when the supernatant liquid was poured off in each case quartz particles were still suspended in the liquid, although the bottles had been subjected to rapid centrifugal treatment for two days at the beginning of this period. The volume of quartz flour not yet settled from the eosine solutions was insufficient to affect the accuracy of the measurements on the volume of solution retained by the compact mass of quartz at the bottom of each bottle. It shows, however, that the eosine dye had deflocculated the quartz particles and that the smallness of the volume of solution, 30 c. c., retained by the settled quartz flour is in all likelihood due to the fact that these particles settled from suspension as single grains or in small aggregates, i. e., deflocculated. The quartz suspensions in gentian violet solution were very noticeably flocculated, save for the high concentrations, where long-continued centrifuging was necessary to clear the solution of suspended quartz particles. And reference to figure 2 will show that the volumes of dye solution retained by quartz are parallel to the condition of the system as regards flocculation, the small volume, 30 c. c., being held by quartz when the concentration of the solution in gentian violet dye is high.

It is evident, then, that the quantity of soluble material absorbed by a soil has a marked influence upon the arrangement of the soil grains into aggregates. Different salts have widely different effects upon the soil structure, and the particular strength of soil solution for which the formation of soil aggregates is a maximum is not the same for each salt. Consequently where mixed solutions, such as those which exist in soils under field conditions, are used it will require a vast deal of experimental work before a prediction can be made as to the exact effect of a particular solution upon the physical condition of a soil.

Nevertheless the above treatment of the effect of absorbed material upon the physical condition gives a good understanding of the agencies at work in the formation of soil structures. And when this point of view is coupled with definite data, such as that in Tables XI to XV, the probable effect of a fertilizer or corrective upon the physical condition of a soil may be given, as well as its addition of mineral plant nutrients. This is especially needed since some fertilizers rich in mineral plant nutrients are ultimately injurious to the physical condition of a soil in a very high degree.

PERCOLATION STUDIES.

RECLAMATION OF BLACK ALKALI SOIL BY LEACHING.

The reclamation of soils containing "black alkali," or soluble carbonates, presents unusual difficulties. These difficulties are due in large part to the fact that soils generally show decidedly higher absorptive powers toward bases present in alkaline solutions than when the solutions are neutral or acid,[a] and that the presence of hydroxides or carbonates of the alkalies frequently induces a "puddling" of the soil, preventing a thorough penetration by water and subsequent removal of the water, with its dissolved contents, by drainage. The latter effect was subjected to a laboratory investigation by Cameron and Patten,[b] using two "black alkali" soils which were in process of reclamation.[c] One, a sample from North Yakima, Wash.,[d] was from the surface 8 inches of the experimental tract north of Wide Hollow Creek. The second sample,[e] from the Toft-Hansen tract at Fresno, Cal., was from the upper 8 inches of soil in a spot plainly showing "black alkali" at the surface. When collected there were only a few scattering spears of grain on this spot, although all about it the grain had made a good stand. When the crust formed by the "alkali" was broken, grain was found which had sprouted but had not been able to push through the crust. A calcium carbonate hardpan occurred about 3 feet below the surface, but was also found at the same depth in adjoining fields on which there was a good stand of barley.

Chemical analyses of the water-soluble salts in these samples by the conventional method[f] of digesting the sample with five times its weight of water gave the results shown in Table XVI. It will be observed that both samples were of the same type of alkali soils, containing, besides the soluble carbonates, notable quantities of sodium sulphate, with much less amounts of other sulphates and chlorides.

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[a] See Bul. No. 30, Bureau of Soils, U. S. Dept. Agr., 1905.

[b] Jour. Am. Chem. Soc., **28**, 1639 (1906).

[c] Bul. No. 42, Bureau of Soils, U. S. Dept. Agr., 1907.

[d] Sample No. 14413, Bureau of Soils collection.

[e] Sample No. 14402, Bureau of Soils collection.

[f] Bul. No. 18, p. 65, Bureau of Soils, U. S. Dept. Agr., 1901.

From the mechanical analyses of these samples (Table XVII), together with their field properties, both the Yakima and Fresno soils would be classified as fine sandy loams.

Table XVI.—*Water-soluble constituents in soils from North Yakima, Wash., and Fresno, Cal., extracted by digesting one part of soil with five parts of water.*

Constituent.	North Yakima.	Fresno.	Constituent.	North Yakima.	Fresno.
	Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
Ca	Tr.	Tr.	Cl	0.03	0.03
Mg	0.02	Tr.	HCO_3	.27	.16
Na	.24	0.13	CO_3	.10	.02
K	.03	.02			
SO_4	.18	.09	Total	.87	.45

Table XVII.—*Mechanical analyses of soils from North Yakima, Wash., and from Fresno, Cal.*

Conventional name.	Diameter.	North Yakima.	Fresno.
	mm.	*Per cent.*	*Per cent.*
Fine gravel	2 to 1	Tr.	0.1
Coarse sand	1 to 0.5	1.3	2.1
Medium sand	0.5 to 0.25	2.5	3.7
Fine sand	0.25 to 0.01	12.8	24.7
Very fine sand	0.01 to 0.05	21.2	33.6
Silt	0.05 to 0.005	48.6	29.5
Clay	0.005 to 0	13.5	6.2

EXPERIMENTAL METHODS.

The method of percolation was essentially the same as that employed by Schreiner and Failyer,[a] with the exception that a constant water pressure was maintained instead of keeping the rate of percolation constant. One hundred grams of soil were placed in a paraffined brass tube fitted below with a short section of a Pasteur-Chamberland filter tube, and distilled water allowed to percolate through the soil under a constant water pressure of 199 cm., or 6.5 feet.

The volume of each percolate was measured, its electrical conductivity taken with a field bridge,[b] and its time of flow recorded. Normal carbonates (CO_3) and bicarbonates (HCO_3) were then determined volumetrically with standard acid potassium sulphate solution and the chlorine titrated with tenth normal silver nitrate solution, using potassium chromate as indicator. Sulphates were not determined, because the amounts here involved are too small to have any great agricultural significance and the analytical difficulties in handling quantities of this magnitude would be unjustifiably great.

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[a] Jour. Phys. Chem., **10**, 239, 361 (1906). Bul. No. 32, Bureau of Soils, U. S. Dept. Agr., 1906.

[b] Bul. No. 15, Bureau of Soils, U. S. Dept. Agr., 1899, p. 15.

RESULTS WITH SOIL FROM NORTH YAKIMA.

The data obtained with the Yakima soil are given in Table XVIII. The first column gives the time during which percolation has been progressing; the second column, the total volume of percolate; the third column, the conductivity of the successive percolates, at 25° C., expressed in reciprocal ohms multiplied by 1,000, which may be converted to "specific conductivity" by multiplying by the cell factor, 3.57. The next three columns give concentrations in the successive leachings, and the last three columns show the total amounts of the several constituents removed from the soil.

TABLE XVIII.—*Extraction of alkali salts from North Yakima soil by leaching.*

Time.	Volume of percolate passed.	Conductivity of successive portions of percolate × 10^3. T=25° C.	Concentration of successive portions of percolate in ppm. of solution.			Total quantity of constituents leached from 100 grams of soil.		
			CO_3.	HCO_3.	Cl.	CO_3.	HCO_3.	Cl.
Hours.	*C. c.*	*Ohms.*	*Ppm.*	*Ppm.*	*Ppm.*	*Gram.*	*Gram.*	*Gram.*
48	37	....	84	1,160	193	0.00304	0.0424	0.00715
120	101	....	196	1,586	110	.0156	.1439	.01420
216	170	5.76	171	753	152	.0274	.1962	.02470
264	242	3.62	223	406	4	.0433	.2252	.02498
312	312	4.07	168	445	2	.0550	.2563	.02512
360	383	3.98	128	403	3	.0641	.2849	.02533
432	473	3.38	89	385	4	.0722	.3199	.02569
480	539	2.94	64	388	4	.0764	.3451	.02595
558	629	2.80	73	321	1	.0829	.3740	.02607
726	739	2.49	73	263	0.7	.0909	.4029	.02615
778	829	2.17	73	218	Tr.	.0974	.4225	....
827	917	2.04	67	221	....	.1034	.4420	....
873	992	1.90	78	158	....	.1093	.4538	....
940	1,097	1.71	78	130	....	.1173	.4675	....
988	1,184	1.77	50	170	....	.1219	.4823	....
1,065	1,314	1.63	42	185	....	.1273	.5065	....
1,114	1,398	1.51	34	164	....	.1301	.5203	....
1,163	1,485	1.33	22	170	....	.1322	.5352	....
1,210	1,562	1.24	27	145	....	.1343	.5470	....
1,259	1,642	1.03	22	127	....	.1361	.5583	....
1,306	1,716	1.03	6	139	....	.1365	.5683	....
1,378	1,831	1.00	8	130	....	.1372	.5733	....
1,443	1,951	.91	11	109	....	.1385	.5864	....
1,499	2,050	.93	11	115	....	.1396	.5978	....
1,566	2,138	.83	8	103	....	.1404	.6069	....
1,614	2,216	.74	6	94	....	....	.6142	....
1,665	2,306	.71	6	85	....	....	.5214	....
1,711	2,378	.68	6	79	....	....	.6271	....
1,785	2,490	.61	6	73	....	....	.6353	....
1,836	2,586	.59	0	79	....	....	.6429	....
1,884	2,673	.59	0	67	....	....	.6487	....
1,932	2,768	.51	0	67	....	....	.6551	....
2,004	2,908	.45	0	67	....	....	.6645	....
2,076	3,028	.48	0	61	....	....	.6718	....
2,148	3,148	.43	0	55	....	....	.6784	....
2,340	3,378	....	0	51	....	....	.6900	....
2,460	3,583	....	0	47	....	....	.6996	....
2,580	3,813	.51	....	42	....	....	.7093	....
2,772	4,088	....	....	42	....	....	.7209	....
2,887	4,276	....	....	39	....	....	.7283	....
3,007	4,526	.48	....	36	....	....	....	....
3,125	4,741	.49	....	36	....	....	....	....
3,246	4,941	.49	....	33	....	....	....	....
3,391	5,201	.44	....	24	....	....	....	....
3,583	5,528	.53	....	9	....	....	....	....
3,803	5,958	.39	....	18	....	....	....	....
3,899	6,142	.42	....	18	....	....	....	....

An inspection of the results presented in Table XVIII shows that while the water passing through the soil is kept under a constant head the rate of percolation is not constant, but varies somewhat from time to time. The first water entering the dry soil runs through quite rapidly, but as soon as the soil becomes saturated it moves much more slowly. Variations in the rate of percolation are subsequently observed, due undoubtedly in some cases to "channeling" in the soil, in some cases probably to "silting up" of channels, and in other cases partly to the fact that as the percolation proceeds the strongly deflocculating action of the alkali diminishes as its quantity decreases, so that the soil behaves as if it suffered a change in texture as well as in structure. For these reasons the concentrations of the successive portions of the percolates, as evidenced by the conductivity as well as by the analyses, do not show a *regularly* progressive change, although on the whole the concentrations become lower and lower as percolation proceeds. These results are in harmony with many field observations where it has been found that the concentration of a drainage water may vary over quite a wide range, depending upon the rate at

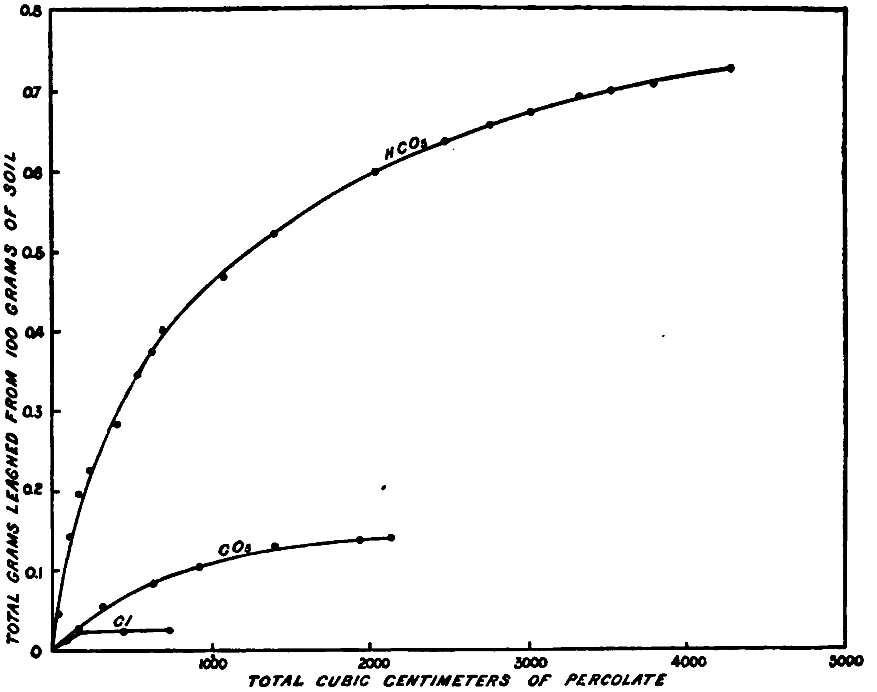

FIG. 3.—Curve showing the total quantities of carbonates, bicarbonates, and chlorine removed by percolating North Yakima black alkali soil with distilled water.

which the applied water moves through the soil and upon the length of time of contact between the water and soil, since considerable time is necessary for equilibrium to result between the salts dissolved and those remaining in the soil.[a]

In the present case chlorides had practically disappeared after 778 hours, when 829 c. c. of water had passed through the soil. Normal carbonates failed to appear in the percolate after 1,614 hours, when 2,216 c. c. of solution had passed. This does not mean, however, that no normal carbonates remained in the soil, for, as has been previously shown in this laboratory,[b] dilution of a normal carbonate causes a change with formation of bicarbonate. It is certain that after 1,614 hours the amount of normal carbonates in the solution has been reduced to a point below that dangerous to plant growth. The alkali, in the form of bicarbonates, however, continued to be leached from the soil after percolation had proceeded for 120 days and a total volume of over 4,200 c. c. had passed through the soil. The results are readily seen in figure 3, where the abscissas are total volume of percolate and the ordinates total grams of the several constituents removed from the soil. The curves are all asymptotic. In the case of the chlorides and normal carbonates, as noted above, the amounts in the successive portions of percolate soon become too small to determine accurately; but in the case of the bicarbonate, amounts could still be readily determined, while the run of the figures in the table and the shape of the curve show that at the termination of the experiment the amount in the successive portions of percolate was slowly diminishing. This is brought out more

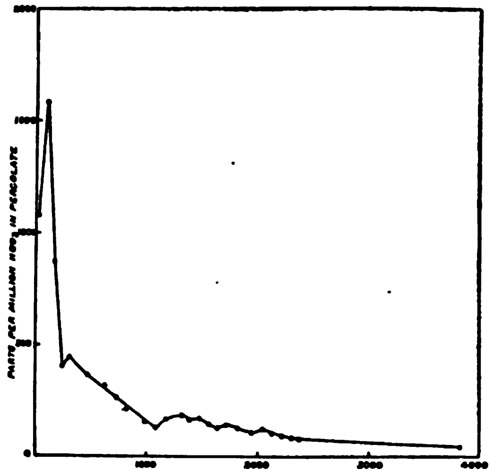

FIG. 4.—Curve showing the quantity of bicarbonate in solution in the successive percolates when North Yakima black alkali is leached with distilled water.

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[a] Bul. No. 33, Bureau of Soils, U. S. Dept. Agr., 1906, and Jour. Am. Chem. Soc., 28, 1229 (1906).

[b] Bul. No. 18, Bureau of Soils, U. S. Dept. Agr., 1901; Jour. Phys. Chem., 5, 537 (1901).

clearly in figure 4, in which the ordinates represent the concentrations in parts per million in successive portions of the percolate. This result is analogous to former leaching experiments made in this laboratory. An inspection of the results for bicarbonates shows, moreover, that if the first few observations be disregarded the leaching curve is described with fair accuracy by the equation

$$\frac{dy}{dv} = K(A-y)$$

proposed by Schreiner and Failyer.[a]

RESULTS WITH SOIL FROM FRESNO.

In working with the Fresno sample the same experimental difficulties were encountered as with the Yakima sample, in that changes in flocculation and channeling materially affected the rate of leaching. In Table XIX are given the rates of leaching during the earlier part of the experiment. The results are more clearly shown in figure 5. It is seen that at first there is a rapid fall in the rate, and then as percolation proceeds, with the formation of channels and an increase in the flocculation due to the partial removal of the alkali, there is an increase in the rate of percolation, becoming quite regular after about 300 c. c. have passed through the soil. It is believed that these changes in the physical condition of the soil as affecting percolation in these experiments are very helpful in showing what may be expected in field practice, although it must be remembered that the intermittent leaching to which the soil is sub-

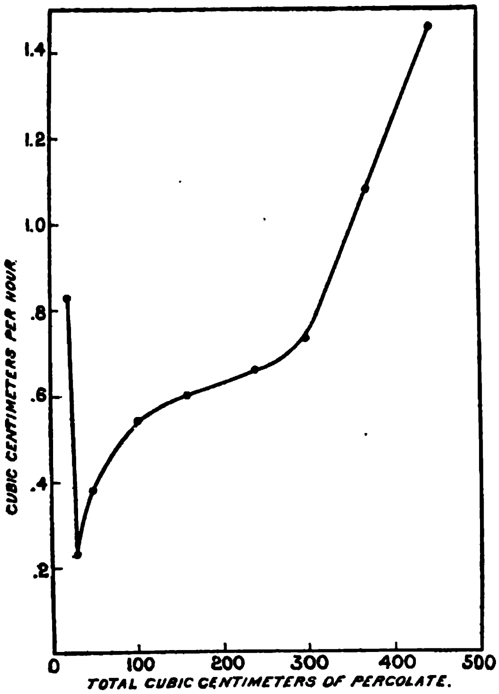

FIG. 5.—Curve showing the progressive change in the rate of percolation as the soluble salts are extracted from Fresno black alkali soil by distilled water.

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[a] Bul. No. 32, Bureau of Soils, U. S. Dept. Agr., 1906.

jected in the field should be more effective than the laboratory results, at least in so far as respects the volume of water required.

In Table XX are given the data obtained from the leachings of the Fresno soil, which are also shown in figures 6 and 7.

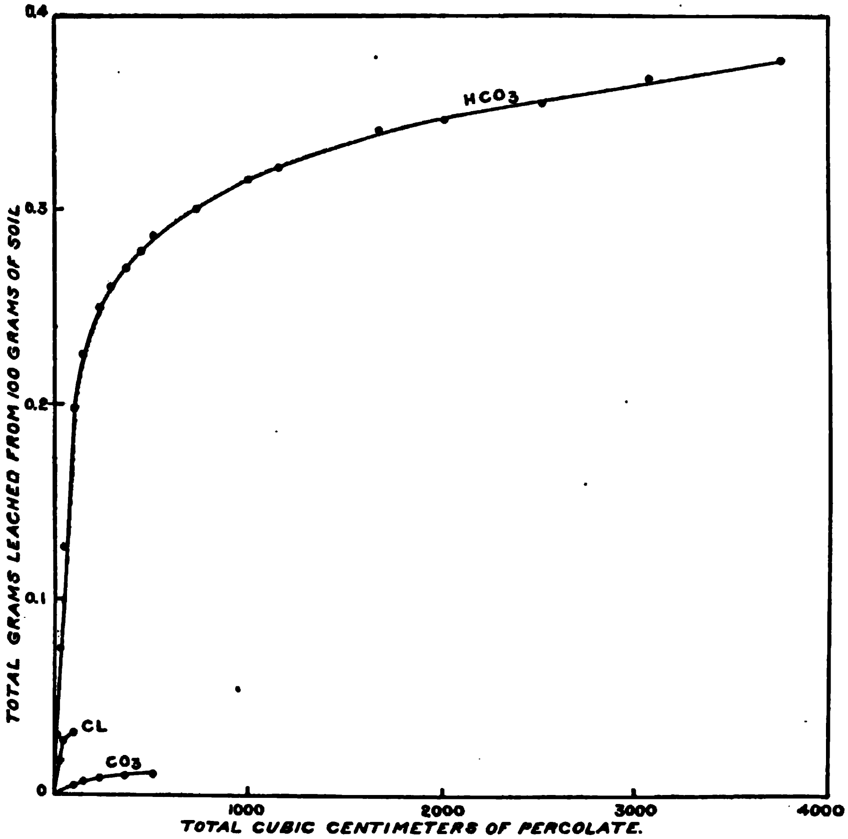

FIG. 6.—Curve showing the total quantities of carbonates, bicarbonates, and chlorine removed by percolating Fresno black alkali soil with distilled water.

TABLE XIX.—*Rate of leaching through soil from Fresno.*

Total percolate.	Quantity per hour.	Total percolate.	Quantity per hour.	Total percolate.	Quantity per hour.
C. c.	*C. c.*	*C. c.*	*C. c.*	*C. c.*	*C. c.*
20	0.83	101	0.54	295	0.73
31	.23	159	.60	368	1.08
49	.38	238	.66	443	1.46

TABLE XX.—*Extraction of alkali salts from Fresno soil by leaching.*

Time.	Volume of percolate passed.	Conductivity of successive portions of percolate × 10³. T=25° C.	Concentration of successive portions of percolate in p.p.m. of solution.			Total quantity of constituents leached from 100 grams of soil.		
			CO_3.	HCO_3.	Cl.	CO_3.	HCO_3.	Cl.
Hours.	*C. c.*	*Mhos.*	*P.p.m.*	*P.p.m.*	*P.p.m.*	*Gram.*	*Gram.*	*Gram.*
24	20	....	....	1,514	352	....	0.0303	0.0070
72	31	....	....	4,125	961	....	.0757	.0176
120	49	....	....	2,860	489	....	.1268	.0264
216	101	7.87	81	1,370	101	0.0042	.1981	.0317
312	159	3.31	45	475	0	.0068	.2256	....
432	238	2.37	23	297	....	.0086	.2489	....
510	295	1.603	12	206	....	.0092	.2606	....
578	368	1.243	12	137	....	.0100	.2706	....
630	444	.842	3	112	....	.0102	.2791	....
679	514	.680	1	105	....	.0103	.2865	....
724	572	.59	0	79	....	....	.2911	....
791	656	.52	....	73	....	....	.2972	....
839	724	.53	....	67	....	....	.3017	....
916	833	.49	....	64	....	....	.3087	....
964	912	.401	....	55	....	....	.3131	....
1,014	1,000	.366	....	33	....	....	.3160	....
1,061	1,083	.361	....	33	....	....	.3187	....
1,110	1,162	.351	....	33	....	....	.3214	....
1,157	1,230	.376	....	43	....	....	.3242	....
1,229	1,345	.417	....	42	....	....	.3291	....
1,301	1,459	.400	....	42	....	....	.3340	....
1,357	1,558	.370	....	37	....	....	.3376	....
1,424	1,667	.334	....	27	....	....	.3406	....
1,472	1,744	.307	....	21	....	....	.3422	....
1,523	1,829	.312	....	19	....	....	.3437	....
1,569	1,905	.283	....	15	....	....	.3449	....
1,643	2,017	.296	....	12	....	....	.3462	....
1,694	2,104	.293	....	15	....	....	.3475	....
1,742	2,185	.293	....	18	....	....	.3490	....
1,790	2,271	.292	....	18	....	....	.3506	....
1,862	2,393	.235	....	15	....	....	.3524	....
1,934	2,513	.209	....	15	....	....	.3542	....
2,006	2,626	.202	....	15	....	....	.3559	....
2,198	2,856	....	....	17	....	....	.3598	....
2,318	3,061	....	....	18	....	....	.3635	....
2,438	3,291	.362	....	18	....	....	.3677	....
2,630	3,575	....	....	25	....	....	.3745	....
2,745	3,756	....	....	15	....	....	.3773	....
2,865	3,961	.331	....	9	....	....	....	....
2,983	4,126	.311	....	6	....	....	....	....
3,128	4,346	.451	....	6	....	....	....	....
3,272	4,534	.797	....	6	....	....	....	....
3,468	4,796	.566	....	3	....	....	....	....
3,688	5,136	.859	....	3	....	....	....	....
3,780	5,284	.407	....	3	....	....	....	....

COMPARISON OF RESULTS FOR THE TWO ALKALI SOILS.

In general the results for Fresno soil are very similar to those obtained with the heavier soil from Yakima, but, as might reasonably be expected, the soluble salts disappear more rapidly from the lighter soil. It is also worthy of note that in the case of the Fresno soil the curve for chlorides (fig. 6) lies above that for normal carbonates, while the reverse is the case with the Yakima soil (fig. 3); but this is not a case of selective absorption, for the Yakima soil contained, initially, much more of the carbonates than did the Fresno sample, while both contained approximately the same quantities of chlorides. Further, the later leachings are more dilute than in the case of the heavier Yakima soil, indicating that the latter possesses a higher absorptive power.

The leachings from the two soil samples here described have resulted in the removal of larger total quantities of soluble salts than is indicated by the standard method of analysis. The quantity of carbonates removed by the leaching process agrees, within the limits of experimental error, with the amounts found by digesting the soil with five times its weight of water. In the case of normal carbonates the continuous leachings as compared with the digestion used in the analytical procedure, showed slightly more in the Yakima soil and somewhat less in the Fresno sample. The differences are, however, so small as to be quite possibly ascribed to analytical errors. But it should be remembered that the addition of much water has the effect of converting a part of the normal carbonates into bicarbonates, and it is in respect to this constituent that the leaching process yields much higher results than does the empirical analytical method, which can not take cognizance of absorption effects. The results on the whole indicate that the empirical procedure with the known inherent defects nevertheless gives a very fair idea of the soluble constituents of the soil where the generally impracticable method of leaching can not be employed.

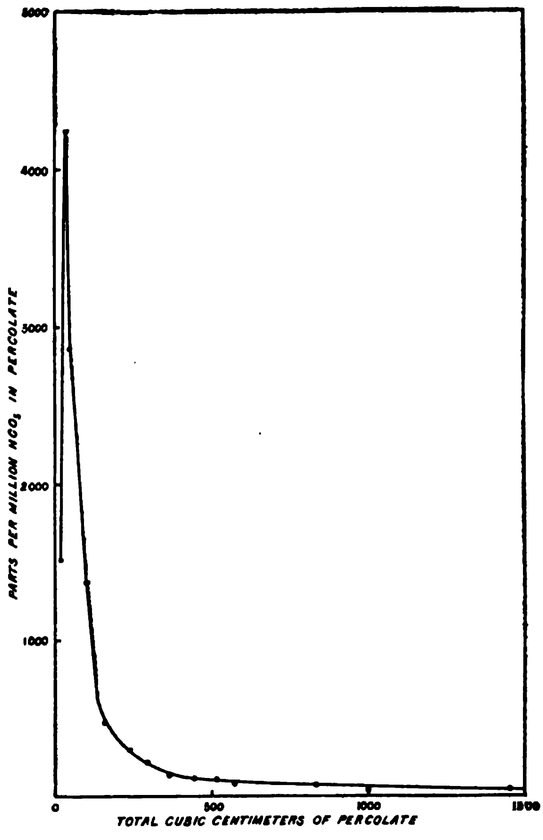

FIG. 7.—Curve showing the quantity of bicarbonate in solution in the successive percolates when Fresno black alkali soil is leached with distilled water.

During the latter half of each percolation experiment the conductivities of the successive percolates show irregular deviations from a fairly constant value, while the titration number for successive percolates slowly diminishes. In the case of the North Yakima soil this mean value of the conductivity, and also the titration numbers, are somewhat higher than for the Fresno soil.

The leaching results presented above indicate the following conclusions: Neutral salts, such as chlorides, in the presence of carbonates are comparatively easy to leach from the soil. With continued leaching of the soils containing "black alkali" there is an increase in the rate at which percolation takes place, due probably to the reduction of the amount of alkali present and to a consequent effect on the physical structure of the soil. With continued leaching there is a comparatively rapid reduction of normal carbonates in the soil water, due in large measure to conversion to bicarbonates. Bicarbonates are rapidly removed at first and then continue to be slowly removed in the soil water in very small quantities, diminishing for an indefinite period. The leaching curves conform fairly well to the rate equation, $\frac{dy}{dv} = K(A-y)$, proposed by Schreiner and Failyer. Soils containing "black alkali" can be reclaimed by leaching (i. e., flooding with underdrainage), but the time and amount of water required is probably much greater than in the case of "white alkali."

EFFICIENCY OF CALCIUM SULPHATE IN REMOVING BLACK ALKALI.

Calcium sulphate has been proposed as a remedy for the injurious effect of black alkali upon growing plants. In order to test the effect of calcium sulphate upon the removal of sodium carbonate and bicarbonate under percolation conditions, four experiments were undertaken. In experiments (1) and (3) of Table XXI, 100 grams of the natural alkali soils from North Yakima, Wash., and from Fresno, Cal., were used. Part of each soil in dry powder (70 grams) was slowly poured into the brass percolation tube and allowed to settle down through the water in it and form a percolation bed. The remainder (30 grams) was meanwhile rubbed up with 10 grams of calcium sulphate and then poured into the tube with the rest of its sample, where it settled, forming a top layer rich in calcium sulphate. Distilled water was then added from time to time, replacing that which passed through the soil. The presence of the calcium sulphate was immediately evident from the rapidity with which the solution passed down through the soil, whereas the untreated natural alkali soils when moistened puddle immediately and in the apparatus used in this work require several feet of water head to produce percolation.

A separate series of experiments, carried out under equilibrium conditions with the North Yakima soil, showed that when the theoretical amount of calcium sulphate required to react with the carbonate and bicarbonate is added and rubbed into the soil, and the soil shaken with water and allowed to settle, the sediment thus obtained occupies a greater volume than that for greater or less additions of the calcium sulphate. This maximum point is as yet not so definitely determined as the above statement might indicate, but nevertheless shows the effect of calcium sulphate upon the *volume* and *openness* of this soil when saturated with water, as it is in the percolation tube. A similar series of experiments with the Fresno soil gave corresponding results, but here the maximum volume of sediment was not reached until *three* times the quantity of calcium sulphate equivalent to the carbonates and bicarbonates in the soil had been added. Experiments (2) and (4) were likewise made with the Yakima and Fresno soils, the experimental conditions being the same as in experiments (1) and (3), save that sodium chloride was added to each soil in sufficient quantity to bring its percentage content up to that of an average black alkali sample from the particular locality to which each soil belongs. This was necessary since these samples proved low in chlorides, and it was desirable to use them in this work because their loss of carbonates and bicarbonates had been already determined under known percolation conditions, and could serve for comparison with this similar series in which calcium sulphate is present.

The sodium chloride was added dry to the alkali soils, rubbed up, water added to make a paste, the soil allowed to dry, and again broken up; calcium sulphate was then worked into the top 30 grams as for experiments (1) and (3).

TABLE XXI.—*Effect of calcium sulphate upon the removal of black alkali by leaching.*

Soil.	Volume of percolate passed.	CaSO$_4$ added.	NaCl added.	Concentration of percolate.			Total constituents leached from 100 grams soil.		
				CO$_3$.	HCO$_3$.	Cl.	CO$_3$.	HCO$_3$.	Cl.
	C. c.	*Grams.*	*Grams.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	*Grams.*	*Grams.*	*Grams.*
North Yakima........	30	10	....	69	656	....	0.002	0.0197	....
	86	....	....	0	468	....	.002	.0459	....
	267	....	....	....	193	....	.002	.0909	....
	296	....	....	....	58	....	.002	.0926	....
	334	....	....	....	40	....	.002	.0936	....
	465	....	....	....	39	....	.002	.099	....
	527	....	....	....	39	....	.002	.1014	....
	730	....	....	....	37	....	.002	.1089	....
	807	....	....	....	51	....	.002	.1148	....
	951	....	....	....	40	....	.002	.1206	....
Do................	30.5	10	0.75	....	223	6,560	....	.0068	0.2002
	45	....	....	10	142	4,780	.00015	.0089	.2672
	177	....	....	60	182	1,333	.008	.0125	.4427
	230	....	....	60	197	42	.0112	.0229	.465
	333	....	....	45	91	10	.0158	.0323	.466
	381	....	....	....	76	0	....	.0360	....
	426	....	....	....	47	0	.0158	.0428	.466
Fresno................	13.5	10	....	....	1,400	....	....	.0189	....
	34	....	....	....	1,515	....	....	.0492	....
	144	....	....	....	223	....	....	.0738	....
	296	....	....	....	46	....	....	.0808	....
	415	....	....	....	42	....	....	.0856	....
	573	....	....	....	52	....	....	.0938	....
	672	....	....	....	49	....	....	.0984	....
Do................	15	10	.335	....	263	10,640	....	.0039	.1596
	122	....	....	15	136	5,250	.0016	.0185	.7216
	173	....	....	....	53	21	....	.0202	.7323
	281	....	....	....	44	0	....	.0250	....
	316	....	....	....	43	0	....	.0265	....
	450	....	....	....	45	0	.0016	.0326	.7323

The headings of Table XXI are self-explanatory. Table XXII contains a summary of the most important points brought out in Table XXI and in the leaching experiments on these soils, already given, using only distilled water.

For the North Yakima soil containing gypsum the quantity of carbonates in the successive percolates decreased continually, whereas in the natural alkali soil an intermediate portion of the percolate had the highest content. Furthermore, the concentration of bicarbonate in the percolates from the soil treated with calcium sulphate were many times lower than the corresponding concentration of the percolate from the untreated soil.

Moreover, using distilled water alone 2,490 c. c. were passed before all the normal carbonate was leached; but with calcium sulphate present, all the normal carbonates came out in the first 30 c. c. of percolate, and this volume of liquid is very nearly that required to saturate this soil with water; therefore it is very likely that the calcium sulphate solution from the top layer of soil in the percolation tube did not react with this first percolate to its full extent, but pushed this solution on before it and out of the soil. That some reaction had taken place is shown by the decrease of nearly one-half (43.4 per cent) in the quantity of bicarbonates present in even this first percolate.

Distilled water leached in all 0.7283 gram bicarbonate from the natural soil, while with calcium sulphate present only 0.1206 gram bicarbonate appeared in the filtrate. Using calcium sulphate, only one-tenth of the volume of water was required to reduce the concentration of bicarbonate in the percolate to 40 parts per million. Experiment 2 indicates that the presence of sodium chloride in quantity does not materially reduce the efficiency of calcium sulphate, since the chloride is rapidly removed. After 177 c. c. of percolate had passed the concentration was only 42 parts per million chlorine in solution and after 333 c. c., no chlorine appeared in the runnings.

For the Fresno soil a comparison of the first six percolates of Table XXI with those of Table XX shows that calcium sulphate has reduced the concentration of the carbonates in the percolates far below that from the natural soil.

Here, too, the calcium sulphate maintained an open structure in the soil favorable to a steady percolation; and the ready access of solution to the soil contributes to the completeness of the conversion of the alkaline carbonates in the soil into the slightly soluble calcium carbonate, with the consequent rapid disappearance of bicarbonate and normal carbonate in the percolate as shown in experiments 3 and 4, Table XXI. In both of these experiments the conversion of normal carbonate to calcium carbonate is seen to be very nearly complete since normal carbonate is practically absent from the leachings, where sodium chloride is added; and it was not found, in the percolate where only calcium sulphate had been added to the soil. To reduce the concentration of the percolate from the natural soil to 40 parts per million bicarbonate, required 1,000 c. c. of water; but on adding calcium sulphate only about one-third of this volume of percolate was needed to reach this same concentration of bicarbonate.

The total quantity of bicarbonate leached by 3,756 c. c. of water from the natural soil was 0.3773 gram. When 672 c. c. of water had been passed throuh the soil treated with calcium sulphate, 0.0984 gram bicarbonate had been removed. Supposing that the concentration in succeeding percolates had remained constant at 40 parts per million bicarbonate, and they undoubtedly averaged much below this figure, the passage of 3,084 c. c. additional water would have carried into solution 0.1234 gram of bicarbonate, making in all 0.2218 gram. This is without doubt much higher than experiment would have shown, but even so is 60 per cent of the quantity which was actually washed from the untreated soil.

TABLE XXII.—*Effect of calcium sulphate upon the removal of black alkali by leaching.*

Soil.	Na_2CO_3 added.	$CaSO_4$ added.	NaCl added.	Carbonate. Maximum CO_3 in solution.	Carbonate. Water required to remove CO_3.	Carbonate. Total CO_3 leached (100 gs. soil).
	Grams.	*Grams.*	*Gram.*	*P. p. m.*	*C. c.*	*Gram.*
North Yakima	....	....	....	223	2,490	0.1404
Do	....	10	....	69	30	.002
Do	....	10	0.75	60	333	.0158
Fresno	....	....	....	81	679	.0103
Do	....	10	....	0	0	0
Do	....	10	.335	15	122	.0016

Soil.	Bicarbonate. Maximum HCO_3 in solution.	Bicarbonate. Minimum HCO_3 in solution.	Bicarbonate. Water required to reduce HCO_3 to minimum.	Bicarbonate. Total HCO_3 leached (100 gs. soil).	Chlorine. Maximum chlorine in solution.	Chlorine. Water required to remove chlorine.	Chlorine. Total chlorine leached.
	P. p. m.	*P. p. m.*	*C. c.*	*Gram.*	*P. p. m.*	*C. c.*	*Gram.*
North Yakima	4,100	39	4,276	0.7283	193	739	0.02615
Do	656	40	334	.1206	....	....	....
Do	223	47	426	.0428	6,560	333	.466
Fresno	4,125	33	1,014	.3773	101	216	.0317
Do	1,515	46	296	.0984	....	....	....
Do	263	45	450	.0326	10,640	173	.7323

The presence of sodium chloride in Yakima black alkali soil causes decrease in the quantity of bicarbonates which must be leached before the percolates reach a concentration below that dangerous to plants. When above 400 c. c. of the liquid had percolated, the solution had reached a fairly steady concentration. At this point over 0.09 gram of bicarbonate has been leached from the soil containing no additional sodium chloride, whereas the same volume of percolate removed about 0.04 gram of bicarbonate from the soil which had been treated with gypsum and sodium chloride. The same phenomenon is met in the case of the Fresno soil. In the case of the Yakima soil the increase in the bicarbonate in the percolates is evidently due to the rapidly decreasing quantity of sodium chloride present. For both soils the final removal of sodium chloride is accompanied by an almost abrupt drop in the concentration of the percolate with respect to bicarbonate.

In conclusion, these experiments indicate that the use of gypsum facilitates the removal of black alkali from soil, although at the same time it adds to the total quantity of alkali present.

ABSORPTION OF POTASSIUM FROM CARBONATE SOLUTION.

The problem of absorption of salts by soils has been studied not only by percolating natural alkali soils with distilled water, determining the quantity of salts removed, but also by the absorption of salt from a percolating salt solution. After introducing into the soil in this manner a considerable quantity of the alkali salt, thus simulating an alkali soil, percolation was commenced with distilled water.

In the following experiments upon the removal and absorption of a base by a soil, a potassium salt was used rather than a sodium salt, on account of the experimental difficulty of determining small quantities of sodium in solution. The normal carbonate of potassium was chosen because previous work gives the form of the curves for the removal of carbonate. The alkaline carbonates, unlike chlorides and phosphates, which were studied by Schreiner and Failyer,[a] have an enormous influence upon the physical condition of the soil.

The experimental difficulty is not so much to regulate the rate of percolation or to keep it sufficiently slow, as to get the solution through the soil at all. One hundred grams of each soil was placed in a paraffined brass tube fitted below with a short section of a Pasteur-Chamberland filter tube, as already described. The solution was percolated through the soil under a head of 6.5 feet water pressure aided by nearly an atmosphere of suction from a filter pump applied below. This pressure was just sufficient for the needs of the experiment.

Four soils, Galveston clay, Marshall silt loam, Hagerstown loam, and Norfolk sand, were percolated with a solution of potassium carbonate containing 444 parts potassium per million parts of solution, and the potassium in the percolates determined colorimetrically[b] for low concentrations and gravimetrically as the chlorplatinate, when the fractions became stronger. The results are given in Tables XXIII to XXVI, and shown graphically in figure 8, which represents the curves of absorption up to the maximum of each, and from that point on the leaching process appears. The data for these leaching curves are contained in Tables XXVII, XXVIII, and XXIX. Each curve in figure 8 gives the total grams of potassium contained by 100 grams of soil—air-dry weight—at each stage of the absorption process.

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[a] Bul. No. 32, Bureau of Soils, U. S. Dept. Agr., 1906; Jour. Phys. Chem., **10**, 239, 361 (1906).

[b] Bul. No. 31, Bureau of Soils, U. S. Dept. Agr., 1906.

The Galveston clay is still absorbing potassium after five months' continuous percolation, during which time 1.13 per cent of potassium has been absorbed by the soil and the concentration of the percolate with respect to potassium has risen to a little over one-third of that for the solution added to the clay, so that we may expect a very considerable quantity of potassium to be absorbed on further percolation. But it seemed inadvisable to prolong the experiment, since the clay had been shown to have a very high absorptive capacity for potassium and would require a very long time for saturation and for subsequent removal of the salts by percolation. Further points on the curve could give, in addition, only the value of the specific absorptive capacity, from a solution of this concentration. This

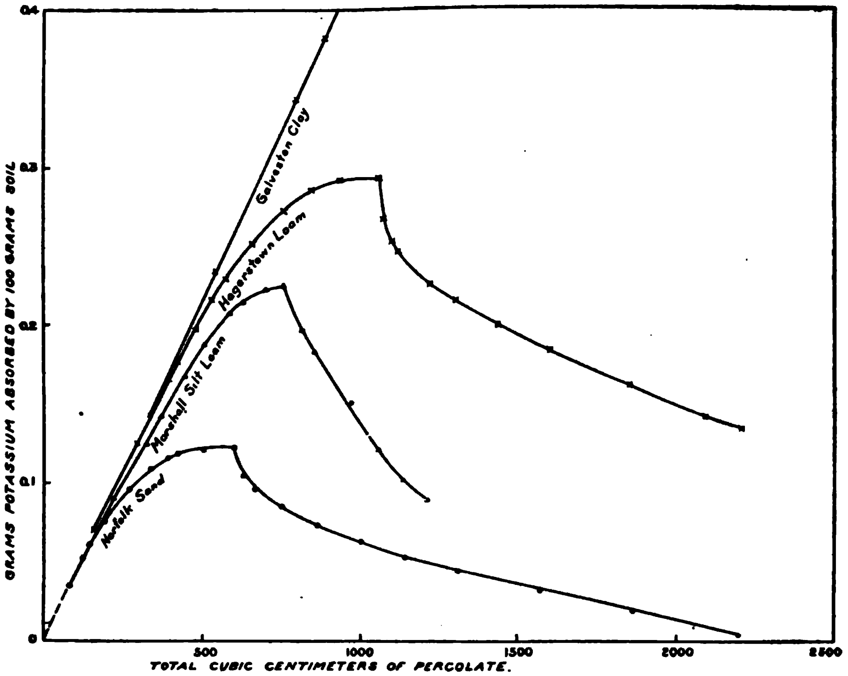

FIG. 8.—Curves showing the total quantity of potassium absorbed from potassium carbonate solution percolating through soils, and the subsequent removal of this absorbed potassium by leaching with distilled water.

absorptive capacity is known for the three other soils used, and the formula $\frac{dy}{dv}=K(A-y)$ proposed by Schreiner and Failyer may be applied.

Table XXIV shows that after some 750 c. c. of the potassium carbonate solution has passed through Marshall silt loam the soil has taken up very nearly all the potassium that it can absorb from a solution of the strength used. Here A, the absorptive capacity of Marshall silt loam for potassium—from this particular concentration of aqueous potassium carbonate—may be taken as 0.230 gram potassium per 100 grams soil. Using this value for A, the results given in Table XXIV conform well to the rate equation of Schreiner and Failyer, $\frac{dy}{dv}=K(A-y)$. For Hagerstown loam, Table XXV, the absorptive capacity, A, is 0.300 gram potassium per 100 grams soil, and the rate of absorption conforms to Schreiner and Failyer's formula, as is also the case for Norfolk sand, whose A, is 0.1226 gram potassium per 100 grams soil, as shown in Table XXVI.

Comparing the soils we see that Hagerstown loam absorbs 0.300 gram, Marshall silt loam 0.230 gram, and Norfolk sand 0.123 gram of potassium per 100 grams of soil. These absorptive capacities are not directly proportional to the areas of the soils per gram as calculated from the mechanical analysis already given.

The absorptive capacity of a soil for potassium from potassium carbonate solution is greater than from potassium chloride solution. Schreiner and Failyer[a] give 1,000 parts per million potassium as the A, for a clay soil in chloride solution containing 200 parts per million potassium; and 650 parts per million as the A for a clay loam under the same conditions. This is a percentage of 0.1 and 0.065, respectively, while Galveston clay absorbed 1.13 per cent, Marshall silt loam 0.23 per cent, Hagerstown loam 0.30 per cent, and Norfolk sand 0.123 per cent potassium—reckoned on the air-dry weight of the soils—from carbonate solution. It is to be remembered that this carbonate solution was more than twice as strong with respect to potassium as the chloride solution used by Schreiner and Failyer. But even taking account of this factor the soils are seen to abstract relatively more potassium from carbonate solution than from chloride solution.

In columns 4 and 5 of the Tables XXIII to XXVI are given the rates of absorption in grams potassium per 100 grams soil per hour, and the rates of percolation in cubic centimeters per hour. The data show a steady decrease in rate of flow as percolation proceeds till a state is reached where the soils seem to form channels and allow the solution to filter faster, and then to close these channels and retard the flow of liquid so that its rate of percolation returns nearly to that prior to the formation of the channels. The initial decrease in rate of flow is not due to packing down of the soils, since they were percolated with distilled water for weeks before any of the potassium carbonate was run through them, but to the puddling or deflocculation produced by the alkaline solution. After the soil is impregnated with alkali the passage of the strong potassium carbonate solution through it is faster than the subsequent flow of distilled water, but as the potassium is washed out the rate increases again.

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[a] Bul. No. 32, Bureau of Soils, U. S. Dept. of Agr., 1906, p. 37; Jour. Phys. Chem., **10**, 361 (1906).

This may be referred to the flocculating and deflocculating action upon the soil grains by the same solute at different concentrations, which has been discussed previously. The production of large floccules would of course permit the solution to pass through more readily and the subsequent breaking down into smaller aggregates would offer a much less permeable percolation bed.

At the beginning of leaching it was necessary to subject the Hagerstown loam to suction under a force of about an atmosphere in addition to the constant head of water, but as leaching proceeded this suction was removed to avoid too rapid percolation. Consequently the rate of percolation for this soil as given in column 5 of Table XXVIII is not exactly comparable with the similar data in Tables XXVII and XXIX. This set of figures on the rate of percolation enables one to compare the rate of absorption with the rate of flow.

The continual decrease in the rate of removal of potassium from these three soils as shown in figure 8, and in the concentration of the percolates given in Tables XXVII, XXVIII, and XXIX, is similar to that for the removal of carbonate, bicarbonate, and chlorine from the natural alkali soils of Yakima and Fresno.

The removal of potassium absorbed by soil from a carbonate solution gives a leaching curve closely resembling that for the removal of potassium absorbed from chloride solution.[a]

The absorption of potassium from carbonate and from chloride solution is likewise described by curves similar in form, and very nearly represented by the formula $\frac{dy}{dv} = K(A - y)$, which also expresses well the rate of absorption and rate of removal of the phosphate radical, PO_4, from soils[a] regardless of what phosphate was used to saturate the soil.

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[a] Bul. No. 32, Bureau of Soils, U. S. Dept. Agr., p. 36.

TABLE XXIII.—*Absorption of potassium from carbonate solution by Galveston clay.*

[100 grams soil. Solution containing 444 parts per million potassium.]

Total percolate.	Potassium in percolate.	Potassium absorbed by 100 grams soil.	Rate of absorption.	Rate of percolation.	Period.
C. c.	*P. p. m.*	*Grams.*	*Gram per hour.*	*C. c. per hour.*	*Hours.*
15	13	0.0065	0.00043	1.00	15.0
25	13	.0108	.00062	1.44	21.9
54	13	.0232	.00062	1.45	41.9
90	9	.0388	.00063	1.46	66.7
158	14	.0679	.00066	1.54	110.9
199	14	.0855	.00066	1.54	137.5
228	16	.0978	.00066	1.54	156.2
271	15	.1162	.00067	1.56	183.8
297	14	.1273	.00068	1.57	200.3
335	15	.1435	.00067	1.57	224.5
411	14	.1707	.00067	1.58	272.5
465	15	.1992	.00069	1.57	305.8
545	17	.2332	.00065	1.53	358.1
802	19	.3423	.00054	1.38	445.6
896	24	.3818	.00054	1.29	518.6
993	32	.4217	.00050	1.22	598.1
1,043	34	.4422	.00048	1.17	640.9
1,168	58	.4904	.00048	1.24	741.9
1,248	76	.5198	.00042	1.16	811.2
1,363	63	.5615	.00044	1.21	906.5
1,464	90	.5970	.00037	1.06	1,002.2
1,566	102	.6319	.00035	1.02	1,102.2
1,663	80	.6671	.00038	1.05	1,194.2
1,763	72	.7042	.00039	1.04	1,260.2
1,868	73	.7431	.00031	.84	1,385.2
1,925	175	.7564	.00020	.84	1,453.2
2,033	102	.7933	.00029	.86	1,578.2
2,154	165	.8270	.00023	.83	1,724.2
2,294	186	.8632	.00022	.82	1,896.2
2,429	167	.9005	.00022	.81	2,073.7
2,582	113	.9512	.00026	.80	2,266.7
2,711	152	.9891	.00020	.68	2,458.2
2,860	149	1.0331	.00029	.71	2,670.0
2,949	170	1.0574	.00009	.54	2,835.5
3,043	195	1.0808	.00005	.22	3,268.0
3,105	178	1.0972	.00011	.42	3,415.0
3,213	145	1.1294	.00017	.56	3,607.0

TABLE XXIV.—*Absorption of potassium from carbonate solution by Marshall silt loam.*

[100 grams soil. Solution containing 444 parts per million potassium.]

Total percolate.	Potassium in percolate.	Potassium absorbed by 100 grams soil.	Rate of absorption.	Rate of percolation.	Period.
C. c.	*P. p. m.*	*Grams.*	*Gram per hour.*	*C. c. per hour.*	*Hours.*
48	7	0.0210	0.00088	2.00	24
145	24	.0615	.00169	4.00	48
225	83	.0904	.00120	3.33	72
325	94	.1254	.00100	2.85	107
372	95	.1418	.00068	1.96	131
403	97	.1526	.00065	1.86	148
445	98	.1674	.00062	1.77	172
469	100	.1757	.00052	1.53	188
508	135	.1877	.00034	1.29	223
558	189	.2004	.00026	1.04	271
590	244	.2066	.00013	.66	319
630	275	.2140	.00016	.87	365
676	318	.2198	.00008	.64	437
696	350	.2217	.00004	.42	485
732	390	.2237	.000028	.50	557
756	400	.2248	.000023	.50	605

TABLE XXV.—*Absorption of potassium from carbonate solution by Hagerstown loam.*

[100 grams soil. Solution containing 444 parts per million potassium.]

Total percolate.	Potassium in percolate.	Potassium absorbed by 100 grams soil.	Rate of absorption.	Rate of percolation.	Period.
C. c.	*P. p. m.*	*Gram.*	*Gram per hour.*	*C. c. per hour.*	*Hours.*
160	6	0.0700	0.00291	6.68	24
292	23	.1245	.00226	5.5	48
392	43	.1648	.00165	4.14	72
478	75	.1966	.00065	1.79	120
530	97	.2146	.00075	2.16	144
573	115	.2287	.00059	1.79	168
630	167	.2445	.00066	2.37	192
657	200	.2513	.00028	1.14	216
696	215	.2602	.00039	1.62	240
753	240	.2718	.00024	1.19	288
796	275	.2790	.00016	.90	336
845	301	.2857	.00015	1.09	380
902	360	.2907	.00007	.80	452
934	406	.2919	.000025	.67	500
983	424	.2929	.000014	.67	572
1,016	428	.2934	.000011	.69	620

TABLE XXVI.—*Absorption of potassium from carbonate solution by Norfolk sand.*

[100 grams soil. Solution containing 444 parts per million potassium.]

Total percolate.	Potassium in percolate.	Potassium absorbed by 100 grams soil.	Rate of absorption.	Rate of percolation.	Period.
C. c.	*P. p. m.*	*Grams.*	*Gram per hour.*	*C. c. per hour.*	*Hours.*
82	5	0.0360	0.00015	3.39	24
122	37	.0523	.000068	1.69	48
193	107	.0762	.0000996	2.96	72
274	193	.0966	.0000425	1.60	120
313	232	.1048	.0000344	1.62	144
338	261	.1098	.0000191	1.04	168
370	305	.1142	.0000183	1.34	192
389	330	.1164	.0000092	.79	216
420	365	.1189	.0000052	1.29	240
464	407	.1205	.0000033	.92	288
502	417	.1216	.0000023	.78	336
546	422	.1226	.0000021	.92	884
600	444	.1226	....	.76	442

TABLE XXVII.—*Leaching of potassium from Marshall silt loam.*

[100 grams, containing 0.2248 gram potassium, absorbed from K_2CO_3 solution.]

Total percolate.	Potassium in percolate.	Potassium left in soil.	Rate of leaching.	Rate of percolation.	Period.
C. c.	*P. p. m.*	*Gram.*	*Gram per hour.*	*C. c. per hour.*	*Hours.*
0	0	0.2248	....	....	0
17	471	.2168	0.000187	0.354	48
36	513	.2070	.000168	.346	103
59	426	.1972	.000123	.290	183
72	410	.1919	.000125	.304	226
95	375	.1833	.000086	.228	327
125	273	.1751	.000050	.183	492
162	151	.1695	.000053	.386	588
194	273	.1607	.000088	.320	688
217	320	.1533	.000039	.123	876
235	350	.1470	.000033	.094	1,069
256	412	.1383	.000033	.080	1,333
301	278	.1258	.000035	.125	1,693
336	337	.1140	.000030	.091	2,078
369	230	.1064	.000020	.088	2,456
390	190	.1024	.000009	.044	2,889
412	202	.0979	.000031	.150	3,036
435	162	.0942	.000019	.120	3,228
456	166	.0907	.0000185	.111	3,417

TABLE XXVIII.—*Leaching of potassium from Hagerstown loam.*

[100 grams, containing 0.2934 gram potassium absorbed from K_2CO_3 solution.]

Total percolate.	Potassium in percolate.	Potassium left in soil.	Rate of leaching.	Rate of percolation.	Period.
C. c.	*P. p. m.*	*Gram.*	*Gram per hour.*	*C. c. per hour.*	*Hours.*
0	0	0.2934			
24	538	.2805	0.00026	0.50	48
51	490	.2673	.00024	.49	103
85	436	.2525	.000107	.43	183
103	311	.2469	.000131	.42	225
144	237	.2376	.000092	.40	326
169	256	.2312	.000093	.36	395
206	145	.2258	.000056	.39	490
243	151	.2202	.000058	.39	586
280	133	.2153	.000044	.37	686
311	90	.2124	.000030	.34	772
346	107	.2087	.000039	.37	868
393	116	.2032	.000047	.38	994
416	114	.2006	.000039	.34	1,082
460	114	.1956	.000040	.35	1,187
511	100	.1905	.000035	.35	1,333
581	90	.1842	.000033	.36	1,525
637	82	.1796	.000027	.34	1,692
704	82	.1741	.000029	.35	1,885
774	87	.1680	.000032	.37	2,077
841	82	.1625	.000026	.32	2,289
896	76	.1583	.000025	.33	2,455
1,032	83	.1470	.000026	.32	2,887
1,077	89	.1430	.000027	.31	3,034
1,136	75	.1386	.000023	.31	3,226
1,191	82	.1341	.000024	.29	3,415

TABLE XXIX.—*Leaching of potassium from Norfolk sand.*

[100 grams, containing 0.1226 gram potassium absorbed from K_2CO_3 solution.]

Total percolate.	Potassium in percolate.	Potassium left in soil.	Rate of leaching.	Rate of percolation.	Period.
C. c.	*P. p. m.*	*Gram.*	*Gram per hour.*	*C. c. per hour*	*Hours.*
0	0	0.1226			
30	582	.1051	0.000314	0.63	48
67	236	.0964	.000159	.67	103
119	138	.0892	.000091	.66	183
148	125	.0856	.000085	.68	226
219	105	.0781	.000074	.70	327
265	97	.0736	.000070	.67	396
335	71	.0686	.000053	.74	491
403	83	.0630	.000059	.71	587
476	75	.0575	.000055	.73	687
541	63	.0534	.000044	.71	779
616	59	.0490	.000046	.78	875
708	53	.0441	.000039	.74	1,000
759	49	.0416	.000037	.75	1,068
857	48	.0369	.000038	.75	1,193
967	42	.0323	.000032	.92	1,339
1,124	44	.0254	.000040	.81	1,510
1,259	41	.0199	.000041	.80	1,678
1,422	43	.0129	.000043	.85	1,871
1,592	44	.0044	.000039	.89	2,063
1,742	34	− .0007	.000024	.71	2,275
1,897	25	− .0046	.0000236	.94	2,330
2,142	21	− .0083	.000019	.57	2,763
2,322	18	− .0116	.000022	1.22	2,910
2,512	4	− .0124	.000004	.99	3,102
2,707	2	− .0128	.0000019	1.08	3,291

Thus we have shown that the removal curves for bicarbonate, carbonate, chlorine, potassium, and phosphate leached from soils are very similar in form.

It has also been demonstrated by these percolation studies that the absorptive capacity of soils is very considerable, large quantities of both acid and basic radicals being retained. These are again released by the soil to fresh additions of water and to the soil solution, as the plants remove the nutrient salts.

SUMMARY.

In the foregoing pages the work on absorption by soils, which has been in progress in the Bureau for some years, has been continued and a further and more complete study has been made of the composition of the solutions and the quantity of material removed from solution by the soil. The literature upon the subject of absorption has been brought together.

In the experiments described the materials used are not always fertilizer salts or constituents of the soil itself, since other substances, particularly certain dyestuffs, are better adapted to obtaining a more detailed knowledge of the mechanism of absorption. In general, it may now be stated that where disturbing influences are not great the mathematical formulation may be made both of the time rate and of the absorption and distribution of the material between the solid and the liquid. The disturbing influences, however, are quite important in most cases actually met in practice, and therefore a detailed study of some of them was undertaken. The most important of these is the change in the physical character of the soil itself, consequent upon the absorption of the dissolved materials. In some cases, notably with acids and with lime, the soils assume a "flocculated" structure, i. e., a great many of the ultimate grains form larger aggregates or "ball together;" and in other cases, especially with alkalies, the soils are deflocculated, each grain standing out separate and distinct from the others. This change in the structure of the soil is of the utmost importance in influencing the physical condition of the soil, which in turn influences the drainage condition, the aeration of the soil, its capacity to hold the soil solution and control its movement through the soil, the composition of the soil solution, the character and rate of the chemical changes taking place in the soil solution; and, in fact, in influencing directly both the physical and chemical factors which are the most important in governing the proper growth of plants.

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Issued April 7, 1909.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF SOILS—BULLETIN No. 53.

MILTON WHITNEY, Chief.

THE ISOLATION OF HARMFUL ORGANIC SUBSTANCES FROM SOILS.

BY

OSWALD SCHREINER AND EDMUND C. SHOREY.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1909.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., May 14, 1908.

Sir: I have the honor to transmit herewith the manuscript of a technical paper entitled, The Isolation of Harmful Organic Substances from Soils, by Oswald Schreiner and Edmund C. Shorey, of this Bureau. This article is the result of a study of several unproductive soils, and deals with the properties of crystalline bodies isolated therefrom.

The material throws considerable additional light upon the question of soil fertility. The manuscript has been gone over carefully with Assistant Secretary Hays, who concurs in my recommendation for its publication as Bulletin No. 53 of the Bureau of Soils.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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THE ISOLATION OF HARMFUL ORGANIC SUBSTANCES FROM SOILS.

THE PRESENCE OF HARMFUL SUBSTANCES.

Investigations into the causes of the infertility of soils have established three facts which may be considered fundamental in any discussion of the subject. These are: First, soils may be infertile because of the presence in them of some substance or substances inimical to plant growth. Second, many plants produce and possibly excrete, as the result of growth, organic compounds which are poisonous to the plants producing them. Third, many of the organic constituents of plants which on the death and decay of vegetation find their way into the soil, or compounds which may arise during subsequent changes in the soil, inhibit growth when presented in solution to the roots of growing plants.

The facts on which these three generalizations are based have been published in detail[a] and will be but briefly presented here.

The essential facts regarding the first proposition are these: Aqueous extracts of soil retain the fertile or infertile properties of the soils from which they are made. A water extract of a poor soil is a poorer medium for the growth of plants than an extract of a good soil. The growth of seedlings in an extract of an infertile soil is often less than in pure distilled water. Since, however, the distilled water contains no mineral nutrients whatever, while the poor soil extract contains some, the diminished growth in the latter must be due to the presence of something harmful, something that hinders the plant's development, even in the presence of the nutrients in the soil solution and those stored in the seed. This simple experiment is sufficient to establish this, but there are a number of other observations thoroughly in accord with the conclusion stated. Dilution of a poor soil extract often makes it a better medium for the growth of seedlings than the original extract. Treatment of such an extract with some absorbing agent, such as carbon black or ferric hydrate, which furnishes no mineral plant food, has the same effect. In other words, any treatment which dilutes the inhibitory material in the soil extract makes it better even when the mineral plant food is diminished at the same time. In further accord with these observations is the fact that the addition of certain chemicals which furnish no plant food often improves poor soil extracts. Pyrogallol is such a compound, the improvement being evidently due to some change in the harmful material brought about by the added compound, or else it enables the plant to overcome the harmful effect.

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[a] Buls. Nos. 23, 28, 36, 40, 47, Bureau of Soils, U. S. Dept. Agr.

The second proposition, viz, that roots may excrete harmful bodies, is based, first, on the behavior of the roots of wheat seedlings when grown in agar-agar in which wheat had been previously grown,[a] and, further, on the fact that from soils in which wheat and cowpeas had been grown until the growth was greatly diminished crystalline substances have been obtained which were found to be inhibitory to wheat and cowpeas, respectively, when these were grown in water solutions of these substances.[b] These substances could not be obtained from these soils before the repeated growth of wheat and cowpeas.

The third proposition has to do with the constituents of plants that on the death and decay of vegetation become part of the soil, in contradistinction to those which may possibly be excreted during the growth of the plant. The number of such compounds which have been studied with respect to their toxicity to plants when compared with the number which may possibly find their way into the soil is very small, and no sweeping conclusions can be drawn as to what classes of compounds are and what are not inhibitory to plant growth. The work done, however,[c] is sufficient to establish the fact that many such constituents are harmful. In view of the great number of such compounds, this work might be continued almost indefinitely, but since many of these plant constituents are undoubtedly soon changed into other compounds in the decay which dead vegetation undergoes in the soil, such continuation does not seem to be the best way in which to attain the end which is the object of fertility studies, viz, profitable rotation and rational fertilization. Once it has been established that some plant constituents are harmful, the attainment of this end seems to lie in the study of such bodies as are actually in the soil under infertile conditions and the way in which they arise in the soil.

To the three general statements made above there may be added, as a supplementary proposition, that the harmful compounds in soils which render them infertile or "exhausted" are organic compounds. There are, of course, soils which are infertile owing to the presence of excess of mineral salts, such as common salt, alkaline carbonates or sulphates, ferrous compounds, etc., but where such is the case the cause is generally easily discernible. With conditions such as these the present studies do not deal. By inhibitory or harmful soil compounds is here meant that residue of the complicated processes of plant life and plant decay which becomes an integral part of the soil; which causes the yield, when the same crop is grown continuously on some soils, to become less and less; which often renders the application of fertilizers necessary in the presence of a sufficiency of mineral plant food; which often compels the abandonment of the crop best suited to climate or market, or else forces a rotation with a less remunerative crop; which prevents the chemist diagnosing the cause of soil infertility by any of the numerous methods of analysis in use; which has rendered of no avail many elaborately planned plat experiments; and which is the cause of a natural succession of wild vegetation not explained by any change of soil or climate.

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[a] Bul. No. 40, Bureau of Soils, U. S. Dept. Agr.

[b] Schreiner and Sullivan, Science, 27, 329 (1908).

[c] Bul. No. 47, Bureau of Soils, U. S. Dept. Agr.

The evidence that the inhibitory bodies which cause infertility are organic compounds is both direct and indirect. As indirect evidence we have the absence of harmful inorganic material; the ready changes in many cases from harmful to nonharmful form by oxidation, whether by the roots of growing plants or by cultivation; the similar change effected by the addition of chemicals, both fertilizer salts and others; the change in injurious properties in many cases on heating, and in other cases the carrying over of the harmful properties on distillation, or removal by burning. Finally, the fact that the roots of growing plants possibly excrete harmful material which behaves as organic matter, and the fact that many organic plant constituents which find their way into the soil are inhibitory to plants, make the conclusion as certain as one based on indirect evidence can be. As final proof that there are in soils organic bodies harmful to plants, there is, as will be shown in the sequel, the isolation and identification of organic bodies from the soil which are inhibitory to plant growth, and which behave in solution as does the extract from an infertile soil.

The end sought in this study of soil fertility is a better understanding of the causes of infertility, and through this the removal, amelioration, or prevention of those bad soil conditions that may be the proximate causes of infertility, even when the real causes are the compounds formed under such conditions.

STATEMENT OF PROBLEM.

The extension of the investigation beyond the generalizations mentioned above involves, among others, three problems, each complex in itself. These are the identity and nature of the harmful substances in soils, their sources or the way in which they get into the soil, and finally the relation of harmful substances to each other, to nontoxic or even beneficial substances, and to added bodies such as fertilizers, both organic and inorganic.

These problems, especially the last stated, are very complex, and it would seem most improbable that the practice of agriculture could ever become scientific, except through the complete clearing up of the questions involved. Every effort should be made, then, to shed light on the identity, source, and general properties, including destruction or alteration, of inhibitory compounds. It is only by this that the practice of agriculture can be placed on the same plane with other great industries which have profited so much by scientific research in the past, a scientific development in which agriculture has not shared to its fullest extent.

With the first of the problems stated, the isolation, identification, and general properties of harmful soil compounds, the present paper is chiefly concerned.

The questions which naturally arise on a first approach to this problem are, first, what is the origin of the organic matter in general in the soil, what kind of substances furnish the material out of which the organic portion of soils is made, and what changes or transformation does it undergo in the soil? Second, are any of the organic compounds which first inquiry may have shown to become part of the soil, or to be formed in the soil, harmful to plants in the small amounts in which they would probably be present?

If in pursuit of this second inquiry it is found that some of the substances which get into the soil, or others which we must conclude are formed in the soil, are harmful, a further question arises. Have any of these substances been found in soils, or may there not be in the soil other substances which, because of insufficient data, have not been considered at all up to this point? The possibility of the presence in soils of compounds, of which neither the presence nor effect could be predicted, or even suspected, at once makes the inquiry the more general one, what do we know of the organic matter in the soil? The problem of the isolation, identification, and study of the general properties of organic soil compounds is, as has been stated, a complex one not only in itself but in its relations to other problems in soil fertility.

SOURCES OF THE ORGANIC MATTER OF SOILS.

An essential difference between soil and a mere mass of sand or disintegrated rock is that the former contains some organic matter. The first step in the transformation of bare rock into soil must be accomplished by the lowest forms of plant life, which obtain the materials necessary for their growth and reproduction from the air, rain water, and mineral matter dissolved from the rock. The death of these furnishes organic matter which can be utilized by higher forms, and thus the process goes on until there is an accumulation of organic matter sufficient, with the disintegrated rock material, to be called an arable soil and furnish a medium suitable for the growth of higher plants and agricultural crops. When the process of soil formation has reached this stage the number of micro-organisms, which at first were probably confined to a few species, is greatly increased, including bacteria and fungi of widely varying habits of growth and varied products resulting from this growth. There is, then, entering into the organic matter of a soil on which wild plants or crops are growing the remains of such parts of these plants as die and any products from the living plants. Still other compounds result from these through the growth of micro-organisms, by the oxidizing action of plant roots, by cultivation or lack of it, and by changes effected by fertilizers. Finally there are remains of micro-organisms themselves. It is probable that animal remains, such as insects and worms, should be accorded a more prominent place as a source of soil organic matter than is usually given them, for the amount of such material returned to the earth is very large. Earthworms are also an important factor, for they not only furnish animal remains, but much of the organic matter of plant origin is changed by passage through their digestive tract.

The final result of these complicated processes, it is hardly necessary to say, must be a mixture fully as complex as the processes through which it arises, and even when the original material has been similar in character the organic residue may be very different under varying conditions of temperature, moisture, aeration, cropping, and the character of micro-organisms present.

It is usual to consider the organic matter of both plants and animals as made up of protein, fats, and carbohydrates, but in addition to these elements there are, particularly in plants, a host of other compounds not included in these groups and which are a source of no small part of the soil organic matter. Among these are resins, hydrocarbons and derivatives, waxes, alkaloids, glucosides, tannins, phenols and their derivatives, acids, aldehydes, etc.

When the complex molecules of proteins, fats, and carbohydrates break down into simpler bodies they split along the same lines of cleavage, depending on the structure of the original molecule, be it through the agency of micro-organisms as in decay, the agency of enzymes in digestion or agents such as acids or alkalies in the laboratory. These simpler bodies, which are termed primary cleavage or degradation products, are no doubt formed in the soil as elsewhere as the first steps of decay.

These primary cleavage products, however, particularly in the case of protein, are subject to still further decomposition through the same or other agencies. These secondary products are very numerous and of widely varying composition, structure, and, of course, chemical and physiological properties. To this is due the very different final products of decay or putrefaction under different conditions. To this variation in secondary decomposition products under different conditions of temperature, moisture, aeration, etc., the varying character of the organic matter in soils is probably due more than to differences in the plant or animal material which originally goes into the soil.

The number of such secondary products that may be formed is very large, and includes gaseous products which are the final stages of the decomposition of the organic matter into its elements, and practically all intermediate compounds between the original complex molecules and the final simple compounds. In other words, there is a continual "building down" process from the original complex molecule to simpler ones and these again into still simpler molecules, and so on down to the elemental stages of matter.

In addition to these various decomposition products in the soil, there are compounds which are built up by micro-organisms from the simpler degradation products. This reversal of the decomposition of the original organic matter into simpler compounds, by synthetic processes effected by micro-organisms, or possibly other agents, adds materially to the complexity of the problem.

Among the unclassified organic compounds spoken of above, such as resins, terpenes, tannins, etc., are some which are very resistant to decomposition by the agents active in the soil, and these may often exist in the soil in their original condition, at least for a time. On the other hand a great many break down into simpler bodies, as do the proteins and carbohydrates.

We have, then, as possible organic compounds in the soil, all plant constituents, compounds of animal origin, their degradation products, both primary and secondary, and also other products built up from these. Any attempt at complete enumeration of these would simply result in a long list of organic compounds with almost every class of such compounds known to science represented, and mention will be made here of but a few of the more prominent ones. Proteins, which are present in all parts of living plants, are complex compounds the constitution of which has not yet been established. These in decay, as has already been stated, break down into simpler bodies, most of which have been thoroughly studied and their composition and constitution well established. Among these simpler bodies, which are nearly all nitrogenous, may be mentioned glycocoll, asparagine, alanine, leucine, phenylalanine, tyrosine, arginine, histidine, and lysine. Fatty acids may be present in plants either as free acids, in combination with glycerol as glycerides, or as part of the more complex molecule of lecithins. Stearic and oleic acids are present in some of these forms in nearly all plants, and there are in addition to these a large number of other fatty acids the distribution of which is in many cases limited to a few related species of plants. The composition and constitution of these is known in most cases, but with the exception of lecithins these fatty bodies are not so readily subject to breaking down in decay as are the proteins, and there is much less known of the products of such breaking down. The lecithins in breaking down give rise also to another class of bodies—choline, neurine, and betaine—all being well-known definite organic compounds of a basic nature.

The numerous substances formed during plant growth which are generally regarded as nonessential in the economy of the plant furnish a large amount of soil organic matter and include a large number of well-defined organic compounds. Among these are the alkaloids, terpenes, phenols, vegetable acids, and derivatives of these bodies. The composition and constitution of many alkaloids is well established; a large number being pyridine or quinoline derivatives, readily break down into simpler bodies like the pyridine or quinoline carboxylic acids, themselves well-defined compounds. The terpenes constitute another class of this kind, being widely distributed and including a large number of compounds, the composition and constitution of which is well known. Pyrocatechol, vanillin, cumarin, coniferin, and vegetable acids such as oxalic, citric, tartaric may be cited as examples of other well-known plant constituents.

It is evident from this brief survey of this phase of the problem that although the organic matter which goes into the soil is of an exceedingly varied and complex character, and that which forms in the soil may be even more so, there is considerable definite information available regarding the character of some of it. A great number of plant constituents, as well as the bodies to which they give rise on decay, are well-known definite chemical compounds. Some of these substances it requires no argument to prove get into the soil on the death of the plants containing them; others may be assumed to be formed in the soil. The question now arises, are any of these harmful to plants in the comparatively small quantity in which we might expect them to be present in soils?

EFFECT OF CERTAIN ORGANIC COMPOUNDS ON PLANTS.

There is in the literature considerable information regarding the injurious effects of various organic compounds on fungi, bacteria, algæ, and some of the higher plants, but for the most part these investigations have been purely physiological and have had no reference to, or direct bearing on, agricultural crops or soil studies. Either the compounds tested have no soil interest, the plants were lower forms, or the measure of inhibition or injury was based on some special function of the plant and not the general one of plant development.

It is not difficult to account for the dearth of data on the injury from organic soil compounds. The prominence given the mineral plant food theory of Liebig and the exclusion of almost every other consideration in dealing with the unproductiveness of soil brought about such a condition that from Liebig's time to the present the idea that organic compounds inhibitory to plant growth might be factors in the infertility or exhaustion of soil had practically no place in the philosophy of agricultural chemists.

Practically all that is known regarding the harmful effect of the organic compounds which get into the soil, or may arise in the soil, has been presented in another bulletin.[a] The most important point—at least in this connection—established by the investigations there reported is that many of the possible organic soil compounds are harmful to plants, some in very small amounts.

From these investigations no general conclusions regarding the connection between effect on plants and chemical constitution were drawn, nor are the data sufficient to form the basis of any complete classification of such bodies. However, the establishing of a relation between effect and chemical constitution was not the object of these investigations, but rather to determine whether some plant constituents which get into the soil or compounds which may arise from them in the soil, are harmful to plants, in small amounts. This has been abundantly proven. It is also a matter of everyday observation that material containing many of the compounds found harmful is constantly being added to the soil. Many of the protein decomposition products, such as asparagine and leucine, not only are not harmful but appear to act as plant nutrients; others again, such as tyrosine, are injurious in quite small amounts. Choline was found to be harmful only in relatively high concentration, while the closely related neurine was injurious in concentrations very much less, and betaine, also closely related to both, was innocuous. The most markedly harmful bodies were found among those deposited within the plant but apparently not a part of the life of the plant. Arbutin, vanillin, cumarin, heliotropine, esculin, terpenes, all of which are found to be very injurious, belong to this class.

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[a] Bul. No. 47, Bureau of Soils, U. S. Dept. of Agr.

Although there may be many plant constituents which are harmful to plants, and although it is evident that many such plant constituents must get into the soil on the death of vegetation, it would seem probable that some of them would be soon changed or destroyed by agents active in the soil so that they could not properly be considered part of the soil nor as factors in soil fertility. Others, however, might persist, since they are likewise strongly poisonous to lower forms of life and not readily oxidized for a longer or shorter period of time under certain soil conditions. This brings up another inquiry. Have any of these plant constituents or known derivatives, which are injurious and which are known to get into the soil, actually been separated from the soil? May there not be in the soil harmful organic compounds, the presence of which is not suspected or can not be predicted? These two questions involve a discussion of our knowledge of soil organic matter, first regarding the presence or absence of known compounds and second as to the possible presence of other compounds which could not have been suggested by the knowledge of the origin of soil organic matter.

PREVIOUS ATTEMPTS TO ISOLATE ORGANIC SOIL COMPOUNDS.

The first part of this inquiry can be very shortly disposed of. There is no record in the literature of any of these plant constituents that must get into the soil, or of any compounds that might be expected to be formed from them in the soil, ever having been isolated from any soil. This can not, however, be taken as evidence that these may not be present, for there is also no record that any individual members of this class have been especially or consistently sought for. There are, moreover, as will be shown in subsequent pages, such difficulties involved in this search that in many cases failure to find, by methods commonly used, would not be proof of their absence. The second phase of this question necessarily involves a somewhat full survey of the literature bearing on the subject and an examination of the claims to recognition of compounds described and named in the literature. This survey will serve as a guide in a systematic search for such soil compounds as are harmful to plants and, moreover, is essential to a thorough understanding of the complexity of the problem in hand and its relation to other problems, and furnishes a basis for attacking this complex problem with a reasonable hope of solving some of the intricate questions of soil fertility.

SEPARATION OF SO-CALLED HUMUS BODIES.

Probably the majority of agronomists, soil chemists, and students of soil fertility in general associate soil organic matter with the term "humus" and with humus only. With some there is the assumption that, when speaking of a soil, humus and organic matter are synonymous, and that any organic matter in the soil not humus is simply the undecomposed remains of plants and animals which have not yet reached the stage of decomposition where they can be properly considered a part of the soil. With others there is the assumption that, although there may be organic matter in the soil not humus, it is of such composition or form that it plays no part in the fertility of the soil, having a purely physical effect. Neither of these assumptions is warranted, as will be shown.

The term "humus," as originally used, had no especial agricultural or scientific significance, being simply another name for dark-colored vegetable mold and later applied to this mold material as a constituent more or less of all soils.

The term has now a more restricted meaning, especially as used by agricultural chemists, being applied more exclusively to the dark-colored organic matter extracted from soils by dilute solutions of sodium or ammonium hydrate and often called "humic acid." It is generally conceded, even by those prone to regard humic acid and allied acids as definite organic bodies, that the organic extract so obtained is a complex mixture and the method of determining humus in use to-day, which is essentially that of Grandeau,[a] is merely an empirical method of determining a portion of the organic matter in the soil. Klaproth [b] or Thomson [c] applied the name "ulmin" to dark-colored amorphous bodies such as those obtained by Vauqulin [d] from the bark of diseased elm trees. Sprengel,[e] who obtained similar bodies from soils applied to these the name "humic acid." In 1838 Berzelius,[f] evidently with the general meaning of the term "humus" in mind, used the term "humin" in describing certain dark-colored constituents of vegetable mold. Following this use of the term "humin," as applied to what was considered to be a definite organic body, a number of other workers took up the study of similar bodies and a number of other terms more or less related soon appeared. This group of workers included

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[a] Traité d'analyses des matières agricoles, p. 148, Paris, 1877. Bul. No. 107, Bureau of Chemistry, U. S. Dept. Agr., p. 19.

[b] De Candolle, Pflanzen-Physiologie, I, 279 (1833).

[c] Jour. prakt. Chem., **21**, 325 (1840).

[d] Ann. Chim., **21**, 39 (1797).

[e] Bul. Soc. Chim., **10**, 173; De Candolle, Pflanzen-Physiologie, I, 280 (1833).

[f] Poggendorff's Ann., **44**, 375 (1838).

Braconnot,[a] Mitscherlich,[b] Boullay,[c] Malaguti,[d] and Mulder.[e] The terms applied to humuslike bodies which have appeared more or less in the literature from that time to the present are associated for the most part with Mulder's name. Mulder had very definite ideas regarding the chemical individuality of these bodies. For instance, he says:[f]

> At present seven different organic substances are known to exist in the soil. They are crenic acid, apocrenic acid, geic acid, humic acid and humin, ulmic acid and ulmin.

These bodies he divided into two groups, one group consisting of crenic and apocrenic acids, the other group embracing all the others. As has been said, many of these terms, particularly humic acid, have come down through the literature of agricultural chemistry to the present and are now used with some writers at least with the same faith with which Mulder used them. According to Mulder these seven organic bodies found in soils were intimately related,[g] and five at least were five distinct steps in the decay of organic matter in the soil. He regarded ulmic acid as the first step in this decay; this on further oxidation yielded humic acid and this in its turn, on still further oxidation, geic acid. Continued oxidation produced apocrenic and finally crenic acid. He ascribed to these the following formulas:[h] Ulmic acid, $C_{40}H_{14}O_{12}$; humic acid, $C_{40}H_{12}O_{12}$; geic acid, $C_{40}H_{12}O_{14}$; apocrenic acid, $C_{48}H_{12}O_{24}$; and crenic acid, $C_{24}H_{12}O_{16}$.[i]

All this reads as though the matter were very simple, but the truth is that, although Mulder may have been in many ways in advance of his time, he was not able at a time when organic chemistry was in its infancy to clear up in so simple a manner one of the most complicated problems this branch of science has to deal with, viz, the composition of the organic matter in the soil.

Early investigators, including Mulder, soon found that sugar, starch, carbohydrates generally, and even albuminous bodies, when treated with strong acids or alkalies gave rise to dark-colored compounds having the same general appearance and properties as the humus bodies arising in the soil through decay. The same names were applied to these compounds and there was a general assumption that those in the soil and those produced in the laboratory were the same. As the number of investigators increased there soon arose disagreements regarding the composition of some of these, particularly humic acid, from several sources, it being found that the carbon content of these different preparations varied quite widely. Mulder attempted to reconcile such conflicting figures by showing that there were several kinds of humus and humic acids different in their character and fixed in their composition.[a]

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[a] Ann. Chim. Phys., **12**, 191 (1819).

[b] Lehrbuch, 3rd edit., I, p. 534.

[c] Ann. Chim. Phys., **43**, 273 (1830).

[d] Ann. Chim. Phys., **59**, 407 (1835).

[e] Jour. prakt. Chem., **21**, 203, 321 (1840); **32**, 321 (1844).

[f] The Chemistry of Vegetable and Animal Physiology, trans. by Fromberg, 1849, p. 146.

[g] Loc. cit., p. 150.

[h] Loc. cit., pp. 150 and 162.

[i] These formulas are on the old basis and to be modernized the hydrogen should be doubled.

He held that the different humic acids might have a different composition due to the presence of one or more molecules of water so held that it could not be driven off at 140° C. For instance, he gives the following formulas:[b]

Humic acid from sugar: $C_{40}H_{12}O_{12}$.
Humic acid from hard turf: $C_{40}H_{12}O_{12}+3HO$.
Humic acid from an arable soil: $C_{40}H_{12}O_{12}+4HO$.

One of the points of issue between these early investigators was whether humic acid and allied bodies contained nitrogen as a component. Mulder held that nitrogen was not a component of these bodies but was present as ammonia, that is, the acids were present in the soil as ammonium salts,[c] and in this connection he says:

> In a good arable soil—that is, one in which the organic constituents are as far as possible decomposed—none of these substances contain nitrogen as a constituent element; all their nitrogen exists in the state of ammonia.

Detmer came to the opposite conclusion[d] on this point, claiming that the nitrogen in humic acid as obtained was present in organic combination. His conclusion was based on the fact that his humic acid, containing nitrogen, when treated with potassium hydrate gave off no ammonia, and only a small amount of nitrogen was given off in treatment with alkaline hypobromate. Later, however, Detmer stated that humic acid could be purified and obtained nitrogen free.[e]

He gave for the acid the formula $C_{60}H_{54}O_{27}$ and also gave the following formulas for salts: $C_{60}H_{46}O_{27}Ca_3(NH_4)_2$, $C_{60}H_{46}O_{27}Fe_2(NH_4)_2$, $C_{60}H_{46}O_{27}Ag_8$.

From time to time there have been reported since the preliminary work outlined above, descriptions and formulas for humic acid and related bodies, the net result being about as many formulas as investigators, the only agreement being a general one of source, preparation, and somewhat vague properties.

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[a] Bul. Sc. Phy. et Nat. Neerl., 1840, pp. 1-102.

[b] The Chemistry of Vegetable and Animal Physiology, p. 154. Formulas on the old basis of O=8.

[c] Loc. cit., p. 146. Chemie der Ackerkrume, II, 256 (1862).

[d] Landw. Vers.-Stat., **14**, 248 (1871).

[e] Jahresb. Fortsch. Chemie, 1873, p. 844.

Ulmic acid, according to Malaguti[a] had the formula $C_{12}H_{12}O_6$. Stein[b] ascribed to the humuslike bodies obtained by the action of hydrochloric acid on sugar the formula $C_{24}H_{18}O_9$. Lefort[c] obtained from rotten wood a humic acid to which he ascribed the formula $C_{24}H_{15}O_{17}$. Liebmann and Lettmayer[d] obtained what they claimed was the ammonium sodium potassium salt of humic acid. The humic acid prepared from this by precipitation contained carbon, 53.6 per cent, and hydrogen, 4.9 per cent. Thenard[e] prepared what he claimed was pure humic acid free from nitrogen and ash and gave the formula $C_{24}H_{10}O_{10}$. Mayer[f] obtained from Dopplerite a humic acid having the formula $C_{17}H_{18}O_5$. Demel[g] described the calcium salt of a humic acid having the formula $C_{24}H_{22}CaO_{12}$. Conrad and Guthzeit[h] obtained by action of acids on carbohydrates a humic acid containing 62.3 to 66.5 per cent carbon and 3.7 to 4.6 per cent hydrogen. Hoppe-Seyler[i] described humic acid obtained from brown coal which had the formula $C_{26}H_{22}O_{10}$; but as the barium salt showed the composition $BaC_{26}H_{22}O_{11}$ he considered the body obtained as the anhydride of an acid $C_{26}H_{24}O_{11}$. Berthelot and Andre[j] by the action of hydrochloric acid on sugar obtained a humic acid to which they gave the formula $C_{18}H_{16}O_7$. This, they claim, when heated to 110° C. gave an anhydride $C_{18}H_{14}O_6$. They further described the properties of this body[k] and stated that it was of the nature of a lactone.

As has already been stated, the object in reviewing the literature on this soil organic matter is for the purpose of arriving at some conclusion regarding the availability of such information as may be found there as a guide in a systematic search for such soil compounds as are harmful to plants. In other words, the chief concern at this stage of the present inquiry is the names and composition of humus bodies as definite organic compounds and their claim to recognition as such, rather than the broader question of the source and method of formation of such bodies and their relation to other bodies in the soil.

Leaving discussion of the results obtained by the workers quoted for subsequent pages, it is not out of place here to note that the most conspicuous feature of this work is the discordant results obtained for bodies bearing the same name and often from the same source.

During the period when the early work on humus bodies was being carried on, there was begun an investigation along another closely related line, although at first sight this close relation might not be apparent. This was the study of the coloring matter in urine, either under normal or pathological conditions, or produced by chemical treatment.

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[a] Ann. Chim. Phys., **59**, 407 (1835).

[b] Ann. Chem., **30**, 84 (1839).

[c] Zeitsch. Chem., 1867, p. 669.

[d] Ber. chem. Ges., **7**, 408 (1874).

[e] Jahresb. Fortsch. Chem., 1876, p. 878.

[f] Landw. Vers.-Stat., **29**, 313 (1883).

[g] Monatsh. Chem., **3**, 763 (1883).

[h] Ber. chem. Ges., **19**, 2850 (1886).

[i] Zeitsch. physiol. Chem., **13**, 109 (1889).

[j] Ann. Chim. Phys., **25**, 364 (1892).

[k] Compt. rend., **141**, 433 (1905).

The early work on this subject was, as might be expected, rather crude, and each investigator obtained different results and gave different and sometimes somewhat fanciful names to what they regarded as definite compounds. Udránszky in 1887 gathered together the loose ends left by these investigators and as a result of his own work stated that the darkening of urine on boiling with acids was due to a humuslike body formed from the reducing substances in the urine.[a] Following this came the work of Hoppe-Seyler[b] and Schmiedeberg[c] along closely related lines and it soon came to be recognized by physiological chemists that plant or animal tissues or fluids, if they contain a carbohydrate group, either free or as part of a more complex molecule, will, if heated with strong acids, give rise to bodies of a humus nature. Schmiedeberg drew attention to the fact that the humus bodies so formed resemble in appearance, properties, and composition the bodies known as melanins and proposed for the artificially prepared bodies the name melanoidins.

The melanins are dark-colored amorphous pigments found in hair, skin, and the choroid coat of the eye and in pathological tissues such as sarcoma. They always contain carbon, oxygen, and nitrogen, and generally either iron or sulphur or both. They all agree in high carbon and low hydrogen content, but otherwise the composition varies according to the source. They do not give any of the reactions for proteins, nor so far as known any other special reactions. They are soluble in alkalies and are precipitated from such solutions by acids. In this, in general composition, color, and the absence of any distinctive reactions, the resemblance between the melanins and the humus bodies of the soil lies. The decomposition products of the melanins have been studied especially by Zdarek and Zeynek,[d] Berdez, Nencki and Sieber,[e] and Hoppe-Seyler,[f] but it is thought by some that the derivatives found by these may have been impurities in the original material examined. In any case there is at present no knowledge of the constitution of these bodies, nor even is it known whether they are mixtures or a group of closely related bodies. Spiegler[g] has pointed out that the melanins may show quite different chemical reactions from the melanoidins.

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[a] Zeitsch. physiol. Chem., **11,** 537 (1887); **12,** 33 (1888).

[b] Zeitsch. physiol. Chem., **13,** 66 (1889).

[c] Archiv. exper. Path. u. Pharm., **39,** 1 (1897).

[d] Zeitsch. physiol. Chem., **36,** 493 (1902).

[e] Archiv. exper. Path. u. Pharm., **20,** 346, 362 (1885); **24,** 17 (1888).

[f] Zeitsch. physiol. Chem., **15,** 179 (1891).

[g] Hofmeister's Beitr., **4,** 40 (1903).

The identity of melanins or natural pigments of animal origin with melanoidins or humus bodies is as yet undetermined, as might well be the case with what, so far as our present knowledge goes, may be mixtures of several amorphous bodies. The fact remains that these two groups of bodies are evidently closely related, and this convergence of two separate lines of investigation, one purely physiological and the other agricultural, till they meet in bodies closely related, if not identical, is of great interest.

Recent work on humus bodies is not very extensive, but what there is tends largely to discredit the claims of the bodies described by earlier workers to recognition as definite chemical compounds. For instance, Post[a] and Muller[b] point out that the humus bodies obtained from soils are often the chitin remains of insects, or the excrement of animals, and Korstyscheff[c] that these humus bodies may often be remains of bacteria and molds. In 1904, Malkomesius and Albert[d] published analyses of humic acids, so called, including the preparations of Merck and Krantz and a natural deposit known as Cassel brown. The figures obtained by them for hydrogen and carbon were approximately the same as those obtained by Detmer for humic acid from turf already quoted.[e] Schermbeck,[f] however, shows that the material analyzed and called humic acid by these authors was in large part a mixture of waxes and resins. As evidence of the variability of the so-called natural humus bodies the work of Cameron and Breazeale[g] may be cited, showing that the carbon in humus obtained in the usual way from a number of typical American soils varied in carbon content from 33.3 per cent to 50 per cent.

Two papers have recently appeared presenting research work on humus bodies which are particularly valuable contributions to our knowledge of these bodies, in that the problem is attacked from new points of view, and by methods not heretofore utilized in the study of these bodies.

Suzuki[h] reports results obtained by treating nitrogen-containing humic acid from different sources with boiling hydrochloric acid and then subjecting the solution obtained to esterification and fractional distillation according to the method of Fischer.[i] By this treatment he separated and identified the esters of most of the monamino and diamino acids and other decomposition products obtained on boiling protein bodies with acids and in addition obtained a quantity of unidentified acids. The conclusion drawn from this work is that humic acid consists for the most part of an insoluble body of a protein nature and that amino bodies are not present as such. The latter part of this conclusion would seem not to be warranted by the work as stated. It is quite possible for some of the decomposition products which were obtained to have been present, though doubtless in smaller amounts, in the humic acid before treatment with boiling acids and to have escaped detection by the tests made. The work, however, does prove that the humic acid examined by him was either of protein nature, a mixture of protein decomposition products, or probably both, together with some as yet unknown bodies.

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[a] Landw. Jahrbücher, 1888, p. 405.

[b] Studien über die natürlichen Humusformen, Berlin, 1887, p. 173.

[c] Annales Agronomiques, **17**, 17 (1891).

[d] Jour. prakt. Chem., **70**, 509 (1904).

[e] Jahresb. über Fortsch. Chem., 1873, p. 844.

[f] Journ. prakt. Chem., **75**, 517 (1907).

[g] Jour. Am. Chem. Soc., **26**, 43 (1904).

[h] Bul. Coll. Agr., Tokyo, **7**, 513 (1907).

[i] Zeitsch. physiol. Chem., **33**, 151, 412 (1901).

In a paper on the chemistry and physiological action of the humic acids[a] Robertson, Irvine, and Dobson report investigations into the chemical composition and constitution of humic acids. These authors obtained four preparations of humic acid—two natural, from peat by treatment with ammonium and potassium hydrate, respectively, and two artificial, by boiling sugar with hydrochloric acid and treating portions of the brown amorphous material so obtained with ammonia and potassium hydrate. They found some difference in composition of the natural preparations, that obtained through ammonia containing 54.24 per cent carbon, while that through potassium hydrate contained 56.67 per cent. The artificial preparations were almost identical in composition, except that the one obtained through ammonia contained 0.76 per cent nitrogen, while the other was nitrogen free. This nitrogen the authors speak of as combined, an assumption which, in view of the great absorptive power of humus bodies for ammonia, is not warranted in the absence of direct evidence of such combination. In these preparations the authors determined methoxyl, CH_3O, by the method of Zeisel[b] and found such a wide difference between the natural and artificial preparations in this respect that the only conclusion justified is that there are important differences in constitution, despite the general agreement of properties and composition. In the humic acid from peat 1.71 to 2.47 per cent CH_3O was found, while in that from sugar 6.47 per cent was obtained.

Considerable space in this paper is devoted to a discussion of the empirical formula of humic acid, but the discussion is based on the assumption that the bodies obtained in the manner stated and called humic acid are definite organic compounds, an assumption which is, as will be shown, questionable.

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[a] Bio-Chem. Jour., **2**, 458 (1907).

[b] Monatsh. Chem., **6**, 989 (1885).

DISCUSSION OF WORK ON HUMUS BODIES.

These results, obtained by investigations scattered over the last seventy years—results in many cases widely at variance with one another and viewed as a whole disconnected and fragmentary—are all that the student of the present day has presented to him in answer to the question, What do we know of humus organic matter in the soil? How much of this is true, how much erroneous, what shall be accepted and what rejected, are obviously questions that must be met at the outset. This has been met either consciously or unconsciously by all workers or writers in agriculture, in ways which may be summed up as follows:

A few agricultural writers accept some of the original names applied to humus bodies, notably humic acid, ulmic acid, and ulmin, and these names they use as though they were definite bodies of well-established composition and constitution. There is probably in the minds of these writers no definite idea of composition or constitution, or even any thought given to that side of the question, but the terms are used consistently and humates and ulmates are spoken of with the same certainty that one might speak of oxalates or citrates.

Other writers, the majority probably, if they have to speak of humus bodies as a class, state that they are probably complex mixtures of little-known bodies, but when they treat the broader subject of plant food and the function of humus in the soil they inconsistently speak of humates, ulmates, etc., with the same assurance as the first class.

A third class holds that the names applied by Mulder to humus bodies are names only; that the acid character of these so-called acids has never been demonstrated; and further, that there is no evidence that the bodies so designated are definite compounds, but rather in most cases that they are complex mixtures. The statement by Cameron and Bell[a] puts the case concisely, "The existence itself of these acids has never been demonstrated * * * No satisfactory descriptions of the physical or chemical properties of these supposed acids, their salts, or characteristic derivatives, have been recorded," and this view can not be too strongly emphasized. Most physiological chemists, to whom the unknown constitution and uncertain composition of humus bodies or melanoidins is the most prominent characteristic, not to speak of the resemblance to melanins, also bodies of unknown constitution and variable composition, likewise concur in this view.

Very brief consideration of the status of organic chemistry at that early time and of the enormous advance made since then, an advance which has given nearly all knowledge included in that branch of science at the present time, can not fail to convince one of the futility, not to say absurdity, of accepting unchallenged the findings of these early workers. Organic chemistry at that time was essentially elementary analysis—the determination of carbon, hydrogen, oxygen, and other elements—and observations on the ordinary physical properties of organic bodies.. All other methods depended on at the present day for establishing the identity of organic compounds were unknown. The records of this early work give meager, if any, information regarding crystalline form of bodies themselves, or of their derivatives, and any mention of melting point or boiling point is lacking. All the present methods of addition, substitution, etc., by which organic compounds are arranged in classes according to structure were unknown or not recognized at their true value. Isomerism was not recognized and modern methods of molecular weight determination were not in use. It made no difference whether a body was amorphous or not, it was only necessary to have a mixture of bodies which remained somewhat constant through simple solution and precipitation, to find its percentage composition of carbon, hydrogen, and oxygen, record some of its common physical properties, and give it a name according to the fancy of the investigator, and it was established as a definite organic compound. If this body or mixture of bodies gave a precipitation with some mineral or alkaline earth, the precipitate was regarded as a salt and the organic mixture so precipitated was called an acid. Chlorophyll, protein, casein, gelatine—bodies regarding which our knowledge at the present day is very incomplete—were spoken of by Mulder and his contemporaries with the same certainty they assumed in regard to oxalic or citric acid, simply because they had all been subjected to elementary analysis and their common properties observed.

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[a] Bul. No. 30, Bureau of Soils, U. S. Dept. Agr., p. 39.

The striving of some of these early workers after simple relations between organic compounds based simply on elementary composition is one of the most prominent features of their work, and in this effort to classify compounds the statements they were led to make regarding bodies which we now know stand in no such relationship as they supposed is perhaps one of the best illustrations of the primitive nature of organic chemistry at that time, and a very convincing argument against accepting any of their work, unless verified in the light of our present knowledge. Speaking of vegetable acids, Mulder says:[a]

> Some acids exist in fruits, and it is worthy of remark that these bear all a simple relation to one another.
>
> Citric acid, $C_4H_2O_4 \times 3 = C_{12}H_6O_{12}$.
> Malic acid, $C_4H_2O_4 \times 2 = C_8H_4O_8$.
> Tartaric acid, $C_4H_2O_5 \times 2 = C_8H_4O_{10}$.
> Protartaric acid, $C_4H_2O_5$.

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[a] The Chemistry of Vegetable and Animal Physiology, trans. Fromberg, 1849, p. 805.

Again, in speaking of "gelatine sugar":[a]

> Sulphuric acid when acting on gelatine forms a kind of sugar containing nitrogen, represented by $C_8H_9N_2O_7$; if from this we subtract $C_6H_5O_5=\frac{1}{2}$ equivalent of cane sugar, there remains $C_2H_4N_2O_2$=urea,

a straining at a relationship between unrelated compounds which appears absurd to us now, but which is based on exactly the same kind of data and methods of reasoning as the relations stated to exist between ulmic, humic, and geic acids.

There is no reason to suppose that these early workers were not competent to perform elementary analyses, and the figures given for percentage composition may be received as accurate for the material analyzed, but there the accuracy stops. There is no reason for accepting the formulas given or for the assumption that the bodies examined are definite compounds. In fact, there is abundant evidence that such is not the case. There is, first, the amorphous, ill-defined nature of the bodies in question, not established as homogeneous by many modern methods available for such purpose; then the various and discordant figures for percentage composition obtained by different workers for what was supposed to be the same body; some evidence already quoted, obtained by workers of the present day, that these bodies really are mixtures; and, finally, very simple experimental evidence establishing this fact by which anyone can easily satisfy himself. If humus bodies be prepared from a soil in the usual way by extracting the soil with dilute alkali and precipitating these bodies from the solution so obtained by acid, there results, on thoroughly washing this precipitate, a body or mixture containing carbon, hydrogen, oxygen, nitrogen, and some ash ingredients. If this precipitate is again dissolved in alkali and precipitated again, there is obtained a mixture containing carbon, hydrogen, oxygen, and nitrogen in quite different proportions from the first precipitate. This can be repeated again and again, each time obtaining different results as to elementary composition. It is of interest to note in this connection that if this be repeated several times a point is reached where the humus precipitate becomes colloidal and passes through the filter. It is evident that by this procedure one could obtain as many humic acids as there were stages in the operation, although the composition varies less and less as one proceeds. In reality, the first precipitate is a mixture, and some of the bodies which seem to be held absorbed in this precipitate are removed by the subsequent operations and appear in the filtrates. This phenomenon is similar to that met with, for instance, in the analysis of the hydrochloric acid extract of a soil. In this case the bulky gelatinous precipitate of iron and alumina hydrates retain some of the lime, and this can not be removed by washing, but can be removed by dissolving the precipitate in acid and reprecipitating. Again, if the first precipitate obtained as above, the so-called humic acid, be treated with solvents, such as alcohol or ether, it is easy to obtain therefrom bodies or mixtures of quite different composition and properties from the original mixture. Further, in the case of the so-called artificial humic acid, for instance, that produced on heating sugar with hydrochloric acid, the composition of the resulting dark-colored amorphous body varies quite widely as influenced by concentration of the acid or length of time of heating.

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[a] Loc. cit., p. 233.

The only conclusion, then, that can be reached from this survey of the literature is that humic acid and allied bodies are mixtures of unknown compounds, and that if there is a single compound making up the major portion of the so-called humic acid, it is as yet of unknown composition, constitution, and properties, and that these bodies, whatever they may turn out to be, may be defined as those dark-colored amorphous compounds arising in soils through the decay of organic matter. In this group, then, would be included those soluble in alkalies, the so-called ulmic and humic acids, and also those insoluble in alkalies, known as ulmin and humin.

As doubtful as is the constitution or even composition of these supposed bodies, even more so is their action, harmful or otherwise, on plants, and no further discussion is called for by the purpose and scope of the present bulletin.

SEPARATION OF NONHUMUS BODIES.

The knowledge to be gleaned from a survey of the literature, of compounds other than these dark-colored mixtures discussed above is somewhat more definite in character. Crenic and apocrenic acid are the only nonhumus bodies recognized by Mulder and others of his day. These acids were first described by Berzelius[a] and further described by Mulder. The status of these bodies is exactly that of humic acid and other soil bodies described by Mulder, and all that has been said regarding the one class may be applied to the other. There is no evidence that any such definite organic compound of the composition and properties described exist in soils.

The possibility of there being other organic nonhumus bodies than these was early recognized, and, as has already been noted, played a part in the early discussion whether humic acid contained nitrogen as a component. It was not, however, until comparatively recent times that anything definite appeared along this line, and all the information so far obtained and suggested centers around the organic nitrogenous compounds. Among workers who contributed to the literature on the question of the character of the nitrogen in humus bodies may be mentioned Loges,[b] who found that a hydrochloric acid extract of a soil contained a nitrogen-holding humus body which yielded a precipitate with phosphotungstic acid, and Eggertz,[a] who found from analyses of thirteen samples of humus that the nitrogen content varied from 2.59 per cent to 6.43 per cent, and that it was present in organic combination, not as ammonia. This conclusion he based on the fact that the nitrogen could not be removed by repeated solution in alkali and precipitation with acids. The probability of the presence in soils of organic nitrogenous compounds not in combination with the humus apparently received very little attention until quite recently.

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[a] Pogg. Ann., **29**, 1 (1833).

[b] Landw. Vers.-Stat., **32**, 201 (1886).

Baumann[b] in 1887 suggested the presence of amino compounds in soils, basing the suggestion on the fact that on boiling soils with hydrochloric acid, ammonium compounds not originally present are formed. Berthelot and Andre[c] concluded from their investigations that the nitrogenous compounds in the soil were chiefly insoluble amids which are easily split into ammonia and soluble amids. Warrington[d] demonstrated the presence of small quantities of soluble amids in soils, and Sestini[e] showed that at least a portion of the soil nitrogen was present as amino acids. Dojarinko[f] obtained from Russian black soils large quantities of amino nitrogen. In 1905 Shorey[g] published results obtained by the application of the methods of Housmann,[h] as modified by Osborne and Harris,[i] to soil. The object of this method is a classification of the decomposition products obtained on boiling protein with strong acids and the results obtained indicate the presence of some of these decomposition products or compounds which give rise to them on boiling with acid. None of these investigations deal with the isolation or identification of any definite amino compound, but are merely attempts to classify a portion of the organic matter, and serve as an indication of what might be found in the soil, and neither the results obtained nor the methods used need be commented on here.

Considering now nitrogenous compounds not of an amino nature, Berthelot and Andre[j] obtained results on the distillation of soils which suggested to them the presence of a pyridine compound.

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[a] Meddelanden fran Konigl. Landbruks-Akademiens Experimentalfält. Stockholm, 1888, pp. 1–66; Centralbl. f. Agr. Chem., 1889, p. 75.

[b] Landw. Vers.-Stat., **33,** 247 (1887).

[c] Compt. rend., **103,** 1101 (1886).

[d] Chem. News, **55,** 27 (1887).

[e] Landw. Vers.-Stat., **51,** 153 (1899).

[f] Landw. Vers.-Stat., **56,** 311 (1902).

[g] Agr. Invest. Hawaii in 1905, Report of Chemist, p. 34.

[h] Zeitsch. physiol. Chem., **27,** 95 (1899).

[i] Jour. Am. Chem. Soc., **22,** 323 (1900).

[j] Compt. rend., **112,** 598 (1891).

Recently Shorey[a] has isolated from an Hawaiian soil a pyridine compound, picoline carboxylic acid, which appears to be the first isolation and identification of a definite crystalline organic compound from a soil.

Of the isolation of nonhumus compounds not containing nitrogen there is no mention in the literature except statements that humic acid, as originally obtained, often contains waxes and resins, and that compounds like acetic acid, formic acid, alcohol, etc., have been detected.

Summing up this survey of the literature, it might be stated that the most conspicuous feature is lack of specific knowledge concerning the organic matter of the soil. The humus bodies are a group of compounds of unknown composition and constitution, some of which seem to resemble the natural animal pigments known as melanins, themselves bodies of indefinite composition and unknown constitution, apparently of a protein nature. There is some evidence that amino compounds are present in certain soils, but beyond this there is no knowledge what members of this large group of nitrogenous bodies may be present. The presence of waxes, resins, and other difficultly decomposable plant residues is indicated, and finally there is the isolation of a single nitrogenous compound picoline carboxylic acid, which doubtless constitutes but a very small portion of the organic matter.

It may not be out of place to remark that this ignorance concerns an important soil ingredient, the presence of which makes soil out of what would otherwise be rock powder or sand. As has been stated in a previous bulletin,[b] the amount of organic matter in ordinary soils is appreciably large, for as the result of analyses of several thousand samples of soil from all parts of the United States, Cameron[c] has shown that the average organic content of soils is 2.06 per cent and of subsoils 0.83 per cent. If the soil be taken as 8 inches deep, there would be an average of 28 tons of organic matter in the soil per acre and 50 tons in the soil and subsoil to the depth of 2 feet.

There are, then, in most soils tons of organic matter, matter which is constantly being changed through the activity of micro- and macroorganisms, through cultivation and fertilization; matter which includes bodies harmful to vegetation, other bodies probably beneficial, and still other bodies wholly inert, but matter about which there is very little chemical knowledge.

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[a] Report Hawaii Agr. Expt. Sta., 1906, p. 37.

[b] Bul. No. 47, Bureau of Soils, U. S. Dept. Agr., p. 10.

[c] Jour. Am. Chem. Soc., **27**, 256 (1905).

EXPERIMENTAL METHODS.

The problem which the student of soil fertility has to face may now be stated tentatively as follows: Many soils are infertile because of the presence in them of organic matter inhibitory to crops. Of this organic matter, which is presumably relatively small in amount, nothing definite is known chemically. Not only this, but on a survey of the investigations into the nature of soil organic matter which have been carried on in the last seventy years it is found that there is nearly a total absence of the proof of the presence of any definite organic compound in the soil, either harmful or otherwise. How can some knowledge be obtained of the chemical nature and properties of these bodies, that there may be intelligent treatment of soils containing them, treatment that will bring about certain destruction or change of the harmful bodies, or prevent their formation, instead of the rule-of-thumb methods now in use. Obviously one way to attain this knowledge is to isolate these bodies from soils and study their properties.

To anyone who realizes the paucity of knowledge of soil organic matter, which has been emphasized in previous pages, it will be apparent that the isolation of any definite organic compounds from the soil is not an easy task. When the task is narrowed down to the isolation of injurious compounds, the difficulties are greatly increased. Before outlining the methods by which this problem has been approached, some of these difficulties should be considered, for the matter resolves itself into a choice of methods to surmount these difficulties.

It is evident, in the first place, that for any organic soil compound to be harmful to plants it must be present in the soil solution; that is, it must be at least slightly soluble. Investigations have shown that many organic compounds stated in the literature to be insoluble are soluble to the extent of a few parts per million at least, and sufficient in many cases to have a harmful effect on plants grown in the solution. The water extract of an infertile soil usually contains but a very small quantity of organic matter, and it is a reasonable presumption that the injurious organic compound is only a part of the total organic matter present. Such being the case, it is evident that the isolation of any organic compound from a water extract of a soil in sufficient amount to establish its identity and study its properties is in most cases a problem that does not come within the limitations of laboratory work. In other words, the amount of soil or soil extract necessary to handle would be too great for ordinary laboratory appliances and methods. This difficulty, due to the small quantity of organic material which must be present in the soil solution, is much increased by the fact that the inhibiting substances are unknown compounds with unknown chemical and physical properties. In many respects the isolation of an injurious substance from an infertile soil and the detection in animal organs of a poison of which the identity, properties, characteristic reactions and symptoms produced are all unknown, are analogous.

With the water extract of a soil practically unavailable as a source of the unknown compounds under the present limitations of laboratory work, and with the lack of methods applicable to such research, the only course open is to make use of all other methods which are known or can be devised for the solution of the soil organic matter, and to attempt to isolate from such solution definite compounds, taking advantage of proven methods, or devising new ones.

Before stating the methods which have been used with different soils in the attempt to isolate from them organic bodies, and the results obtained thereby, there are a few facts regarding the soil organic matter which are true more or less for any soil and which should be kept in mind throughout the discussion of the subject. The organic matter in soils is generally but little soluble at ordinary temperatures in neutral solvents, such as alcohol, ether, or chloroform. Dilute acids at ordinary temperatures have also little solvent action on soil organic matter, and if heated there is usually a change effected in the constitution of some of the organic bodies. Dilute alkalies at ordinary temperatures dissolve relatively large quantities of soil organic matter; in fact, in the case of some soils, nearly the whole of the organic matter can be so dissolved by repeated treatments. This treatment of soils with dilute alkalies, although it may in some cases effect a change in the constitution of some of the organic compounds, especially those nitrogenous, seems at present the only method of effecting the solution of a large part of the organic matter with the minimum chance of changing the character of the compounds sought, and for this reason was the first method used in the attempt to isolate harmful organic bodies from the soil.

SEPARATION OF PICOLINE CARBOXYLIC ACID.

The soil first treated in this way was from Takoma Park, Md., and is fully described in a former bulletin.[a] This soil, which is characterized physically by large percentages of clay, silt, and coarse sand, and very little of the intermediate material, is quite light in color and contains, contrary to what might be expected from its appearance, 3 per cent organic matter. It contains 0.1 per cent nitrogen, and analyses of both water and acid solutions indicate the presence of sufficient mineral plant food for ordinary crops. It is, however, an exceedingly infertile soil and does not respond readily to treatment with either stable manure or commercial fertilizers. A bacteriological examination of a sample of this soil by Mr. Karl F. Kellerman, of the Bureau of Plant Industry, showed this to be rather low in bacterial content though active in denitrification.

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[a] Bul. No. 28, Bureau of Soils, U. S. Dept. Agr.

The water extract of this soil is a poor medium for the growth of wheat seedlings, but is much improved by treatment with carbon black, by dilution, and by the addition of pyrogallol or calcium carbonate. In other words, field observations of this soil indicate that something other than lack of plant food is the cause of infertility, and laboratory observations confirm this and in addition indicate that this infertility is due to the presence of some harmful substance.

When the soil is treated with a 2 per cent solution of sodium hydrate there results a dark-colored solution, the so-called humus extract. If this solution after separation from the soil residue be treated with an excess of acid a flocculent dark-colored precipitate is formed, the so-called humic acid. The filtrate from this is dark colored but much lighter than the original extract and contains a portion of the organic matter. On bringing this extract to neutrality by the addition of sodium hydrate there is formed a further precipitate containing both organic and mineral matter. The neutral filtrate from this is still colored dark yellow and contains a considerable portion of the organic matter originally extracted from the soil by sodium hydrate. By dissolving both of the above precipitates again in sodium hydrate and repeating the operations of acidifying, filtering, neutralizing, and again filtering, there can be obtained a still further quantity of organic matter in neutral solution, which can be mixed with the first portion.

This process results in a neutral solution containing some of the organic matter and a comparatively large amount of a sodium salt resulting from the neutralization of the sodium hydrate used. This neutral solution of soil organic matter gives precipitates upon the addition of a number of mineral salts such as basic lead acetate, cupric acetate, mercuric nitrate, and silver nitrate, precipitates which contain organic matter and are usually nitrogenous.

In this method of obtaining a neutral solution of soil organic matter, the amount so obtained in solution seems to be approximately the same, whether hydrochloric, sulphuric, or nitric acid be used for neutralizing; acetic acid, however, usually gives a smaller amount in solution than the mineral acids. The final treatment to which the solution is to be subjected must decide what acid is used throughout, e. g., hydrochloric acid would not be used if there were any intention of using silver nitrate as a precipitant, nor sulphuric acid if lead subacetate was to be used.

METHOD OF ISOLATION.

The method finally adopted for this particular soil was to treat it for twenty-four hours with frequent shaking with 2 per cent solution of sodium hydrate free from chlorides, allowed to stand until the soil residue settled and the dark-colored solution siphoned off. To this was added a slight excess of nitric acid free from the lower oxides of nitrogen and the flocculent humus precipitate filtered off. The acid filtrate was then exactly neutralized by the addition of sodium hydrate and the precipitate so formed filtered off. To the resulting neutral solution was added a solution of silver nitrate and the precipitate formed, which was slight in amount, was allowed to settle, the clear liquor decanted, and the precipitate collected on a filter and washed with a small quantity of water. The precipitate while still moist was suspended in water and treated with hydrogen sulphide, the silver sulphide filtered off, and the filtrate evaporated to small volume on a water bath and allowed to cool slowly. There was thus obtained a more or less colored residue in which crystals formed. The crystals were separated from the mother liquor, washed with a small quantity of cold water, dissolved in hot water, and precipitated again with silver nitrate. Filtration, treatment with hydrogen sulphide, etc., being now repeated, the crystals were usually obtained fairly free from color and could be further purified by recrystallization from water.

PROPERTIES OF THE ISOLATED COMPOUND.

The crystals obtained are little soluble in cold water, easily in hot, little soluble in alcohol, and almost insoluble in ether. From water the compound separates in oblique prismatic crystals with water of crystallization which they lose at 100° C. In Plate I, figure 1, is shown a photomicrograph of these crystals obtained by allowing a rather dilute solution in hot water to cool slowly, and figure 2 shows the crystals obtained by cooling a rather concentrated solution in water. The latter crystals are usually very thin plates, superimposed, forming large scale-like masses and giving very brilliant color effects with polarized light. The substance sublimes unchanged on heating in an open dish and does not melt in a capillary tube at 300° C. A water solution is faintly acid to litmus, and when neutralized does not give a precipitate with either barium chloride, calcium chloride, cadmium sulphate, or lead acetate. Cupric acetate gives a bluish crystalline precipitate, insoluble in cold water. Silver nitrate gives a flocculent amorphous precipitate.

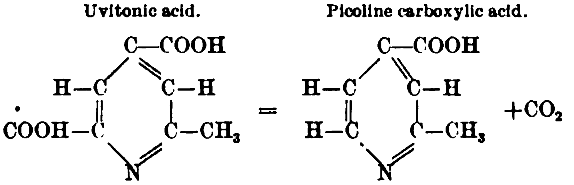
IDENTIFICATION AS PICOLINE CARBOXYLIC ACID.

The crystals have, therefore, the appearance and properties of picoline carboxylic acid, which, as stated, had been isolated by Shorey from a Hawaiian soil by the same method. The compound from Hawaiian soil was further identified as picoline carboxylic acid by its corresponding water of crystallization, its nitrogen content, the chlorine content of the hydrochloride, and its conversion into lutidinic acid on oxidation. The last-named acid is characterized by crystallizing in leaflets little soluble in cold water and melting at 239° C., and giving a yellowish or orange color with ferrous sulphate.

The preparation obtained from the Takoma soil having the properties stated above was compared with that obtained from Hawaiian soil, and also with picoline carboxylic acid prepared artificially in the laboratory, and found to correspond throughout.

PICOLINE CARBOXYLIC ACID AND RELATED COMPOUNDS.

Picoline carboxylic acid, which has heretofore been known as a laboratory product only, has been described by Böttinger[a] and can be prepared by heating uvitonic acid to 274° C. Uvitonic acid, which is methyl pyridine carboxylic acid, breaks up at this temperature into carbon dioxide and picoline carboxylic acid, as shown below:



Uvitonic acid can be easily prepared in the laboratory by treating pyruvic acid with alcoholic ammonia, separating the precipitate formed, washing it with ether, dissolving it in water, and precipitating the free acid by the addition of sulphuric acid, as described by Böttinger.[b]

Leaving the toxicity of picoline carboxylic acid for discussion in subsequent pages in connection with other substances found in soils, it may be said here that it was found to be not very harmful to wheat seedlings, while the nearly related uvitonic acid was quite so. While this slight harmful effect and the apparently very small amount of this body in the Takoma soil make it improbable that it is responsible for more than a small part of the infertility of that soil, its close connection with the uvitonic acid and other closely related acids, such as pyridine tricarboxylic acid,[a] known to be antiseptic, justifies the suspicion that there may be present some other pyridine compound either a source of or a product of the one actually found and one which might be the active cause of infertility.

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[a] Ber. chem. Ges., **14**, 67 (1881); **17**, 92 (1884).

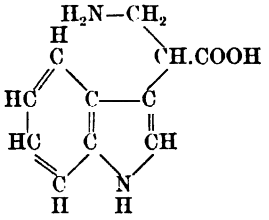
[b] Ann. Chem., **188**, 330 (1877); **208**, 138 (1881); Ber. chem. Ges., **13**, 2032 (1880).

POSSIBLE ORIGIN OF PICOLINE CARBOXYLIC ACID.

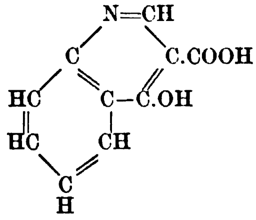
Regarding the origin of the picoline carboxylic acid in the soil, very little can be said at the present time, yet it may not be out of place to call attention to a few facts in connection therewith. In the laboratory picoline carboxylic acid can be formed from pyruvic acid and ammonia through the intermediary compound, uvitonic acid, by splitting off carbon dioxide. Pyruvic acid has been shown by Mörner[b] to be a constant secondary decomposition product of protein, and as such might be formed in the soil; in fact, there are some indications of its presence along with picoline carboxylic acid in the soil under investigation. Should this be the case, then it is not impossible that the remaining steps in the formation of picoline carboxylic acid should take place in the soil, although no reaction whatever for the uvitonic acid could be obtained. The most that can be said, therefore, is that the picoline carboxylic acid may possibly have arisen as the result of the splitting and decomposition of protein in the soil.

A further point of interest in regard to the formation of the pyridine nucleus in the soil through the decomposition of protein is shown by the formation of pyridine on reduction of the melanoidins or humin substances, resulting from the dissociation of protein, as demonstrated by Samuely.[c] Hopkins and Cole[d] have further shown that tryptophane, one of the dissociation products of protein, is readily changed to dark-colored humin substances on boiling with acids, or even with water, and Ellinger[e] has suggested for trytophane the structural formula:

Tryptophane.



Kynurenic acid.



which, as is readily seen, contains the possibility of the pyridine closure, as illustrated by its transformation into kynurenic acid. All

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[a] Rademaker, Med. Herald, **19,** 107 (1887).

[b] Zeitsch. physiol. Chem., **42,** 121 (1904).

[c] Hofmeister's Beitr., **2,** 355 (1902).

[d] Jour. Physiol., **27,** 418 (1901); **29,** 451 (1903).

[e] Zeitsch. physiol. Chem., **43,** 325 (1904).

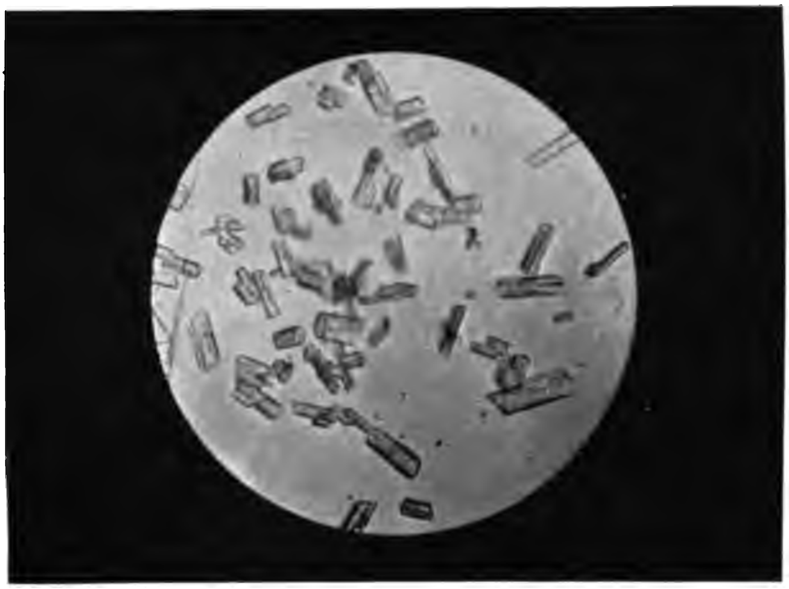

FIG. 1.—CRYSTALS OF PICOLINE CARBOXYLIC ACID OBTAINED FROM SOILS, FORMED FROM A DILUTE AQUEOUS SOLUTION.

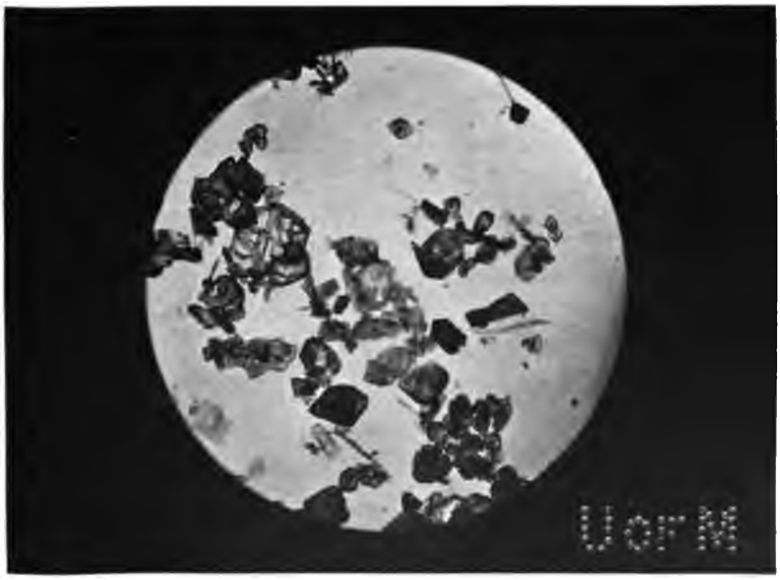

FIG. 2.—CRYSTALS OF PICOLINE CARBOXYLIC ACID OBTAINED FROM SOILS, FORMED FROM A CONCENTRATED AQUEOUS SOLUTION.

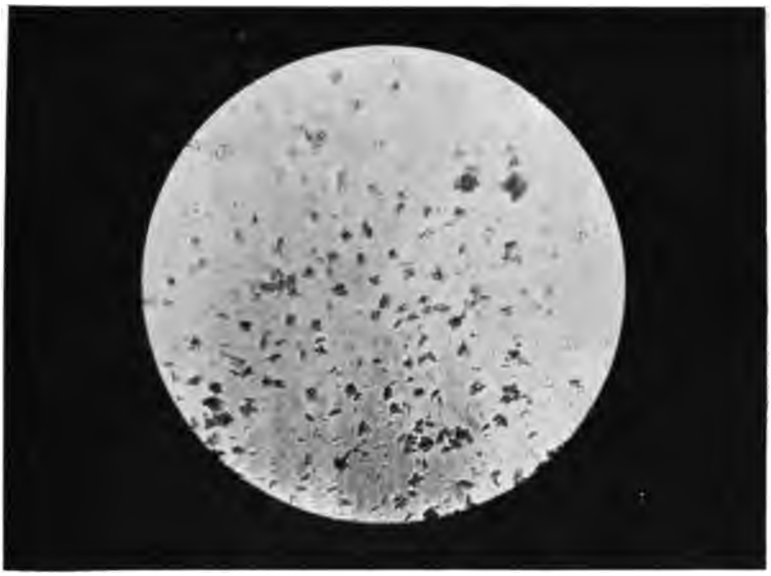

FIG. 1.—CRYSTALS OF DIHYDROXYSTEARIC ACID OBTAINED FROM SOILS.

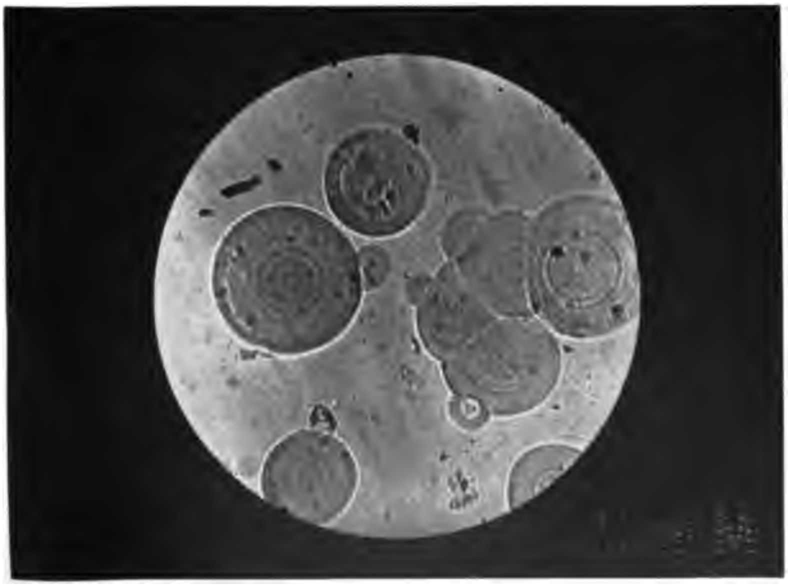

FIG. 2.—CONCRETIONS OF THE BARIUM SALT OF DIHYDROXYSTEARIC ACID.

these facts indicate strongly that the origin of the pyridine ring in the soil, whether it be as picoline carboxylic acid or other pyridine derivative, lies most probably in the decomposition of protein bodies.

THE PRESENCE OF OTHER COMPOUNDS INDICATED.

There has been gathered some evidence of the presence of pyruvic acid in the Takoma soil, but this evidence is as yet indicative only. This evidence, stated briefly, is as follows: When the neutral soil extract obtained as outlined above is made alkaline with sodium hydrate and then a solution of iodine in potassium iodide added there is formed in a short time at room temperature a precipitate of iodoform. The same precipitate can be obtained by treating the original sodium hydrate extract of the soil with iodine reagent. The iodoform so obtained was identified, after recrystallizing, by its melting point and by its characteristic crystalline form as well as its odor. Pyruvic acid forms iodoform when treated in this way, but this is true of other acids, for instance, lævulinic. Again, when the neutral soil extract is made acid and treated with a solution of phenylhydrazine hydrochlorate there is produced in a short time a reddish-colored micro-crystalline precipitate which soon tends to become resinous. It was not found possible by any means so far tried to purify this precipitate so as to obtain any characteristic crystalline form or constant melting point. The phenylhydrazone of pyruvic acid crystallizes in needles and melts at 178° to 183° C. It is evident that if pyruvic acid is present there is also present another compound giving a precipitate with phenylhydrazine. Bülow[a] has described a reaction of the phenylhydrazones which he states is characteristic. When the phenylhydrazone is treated with concentrated sulphuric acid and dichromate of potassium there is produced a purplish color. This color is produced by the phenylhydrazone precipitate from the soil extract and by the pure phenylhydrazone of pyruvic acid.

Simon[b] has described a color reaction of pyruvic acid which he states is characteristic. This depends on the blue color given by sodium nitroprusside and ammonia when added to dilute solution of pyruvic acid. When the neutral soil extract is treated with these reagents there is produced a very slight greenish color, which, since the soil extract is orange colored, might be expected in the presence of small amounts of pyruvic acid. The delicacy of the reaction was tested by adding known quantities of pyruvic acid to the neutral soil extract and adding the reagents, and it was found that the reaction was not at all delicate in the presence of the other material present in the soil extract, as much as 500 parts per million being required to give the characteristic blue color, lower concentrations producing greenish shades. These reactions indicate at least the probable presence of pyruvic acid as well as other bodies not yet isolated.

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[a] Ann. Chem., **236,** 195 (1886).

[b] Compt. rend., **125,** 534 (1897).

Pyruvic acid was found to be quite injurious to wheat seedlings, but was not so when neutralized with sodium hydrate, and if present in the soil its activity as a factor in infertility would no doubt depend on the form in which it might be present. Apart from this the possible presence of this acid in the soil is of interest, for it may be that through the agency of ammonia in the soil the change from the open chain nonnitrogenous pyruvic acid to the ring form nitrogenous uvitonic acid could be effected, as is done in the laboratory with alcoholic ammonia. Uvitonic acid has been sought for in the various soil extracts, but so far with no indication that it is present.

When picoline carboxylic acid is prepared from the neutral soil extract by the method stated above there is separated from the crystals a dark-colored mother liquor containing nitrogen. When this is evaporated nearly to dryness there usually separates a further small quantity of picoline carboxylic acid, but no other crystalline body has been obtained or observed. The mother liquor at this stage, however, is thick and viscous and of such a nature that crystallization of any body present would be difficult. When the mother liquor is evaporated completely to dryness and then taken up again with water there is found a quantity of amorphous colored matter which does not redissolve.

When the dry residue obtained by evaporating the mother liquor to dryness is heated with caustic lime there is given off an odor of crude pyridine, indicating a still further quantity of picoline carboxylic acid or of some other pyridine compound. When the mother liquor from which picoline carboxylic acid has been separated is made alkaline with sodium carbonate and treated with a solution of diazo sulphanilic acid, a dark-red color is slowly formed. The color produced by this reagent with certain organic compounds was first noticed by Ehrlich[a] and further described by Pauly,[b] who found that it could be used for the detection of histidine in the absence of tyrosine. Histidine gives with this reagent a dark-red color which remains red on dilution, and no other protein decomposition product except tyrosine gives this color, all others giving yellow colors which disappear on dilution. According to Pauly the distinctive color given by histidine and diazo sulphanilic acid is due to the imidoazol group, histidine being α-amino β-imidoazol propionic acid. The color obtained by treating this soil material with diazo sulphanilic acid does not appear to be that obtained with histidine, being slower in appearing and soon losing the red tint on dilution. The same color can be obtained in the distillate on distilling the original soil with steam, and is much more pronounced if the soil be made slightly alkaline before distillation. Other organic compounds than those mentioned in the literature were found to give this color, for instance, arbutin[a] and piperidine, so that the most that can be said of this reaction is that it indicates the presence of some body not yet isolated or identified.

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[a] Zeitsch. klinische Med., **5**, 285 (1882).

[b] Zeitsch. physiol. Chem., **42**, 508 (1904); **44**, 159 (1905).

SEPARATION OF DIHYDROXYSTEARIC ACID.

The comparatively slight harmful effect of picoline carboxylic acid, the only compound up to this point isolated from the Takoma soil, coupled with the apparently very small quantity present in this soil, led to the conclusion that there must be some substances of much more injurious character than this present—substances perhaps not in any way connected with the one obtained or others indicated. With the object of, if possible, obtaining such other bodies from this soil a number of other methods were tried.

METHOD OF ISOLATION.

One which finally gave definite results was as follows: The soil was treated with 2 per cent sodium hydrate solution as in the method first used. This alkaline extract was made acid with a slight excess of acetic acid and filtered from the humus precipitate. There was thus obtained a dark-colored extract containing organic matter, sodium acetate, acetic acid, and some mineral matter from the soil. This acid extract was shaken out with ether and the ether allowed to evaporate on the surface of a small quantity of water in a warm place. The ether on evaporating left on the surface of the water some colored resinous material, together with nodules or concretions of a crystalline body. On heating the water to boiling these crystals went into solution, while the resinous matter remained undissolved, and on pouring the solution into a filter previously wet with hot water the resinous material remained in the filter. On cooling the solution so obtained, crystals separated, which generally appeared as very small plates or leaflets arranged in radiating clusters. These if still colored could be purified by solution in hot water and filtering as before. This body, which is white when pure, melts at 98° to 99° C., is little soluble in cold water, somewhat readily in hot, and quite soluble in alcohol or ether. A water solution is acid to litmus and decomposes barium or calcium carbonate, forming the corresponding salts, which are difficultly soluble in cold water. This body was found to be quite harmful to wheat seedlings.

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[a] Bul. No. 47, Bureau of Soils, U. S. Dept. Agr.

ISOLATION FROM SEVERAL SOILS.

With the object of extending the research to other soils, six more or less infertile soils, selected from near Arlington, Va., Indianapolis, Ind., Center Hall, Pa., State College, Pa., Pulaski, Tenn., as well as that from Takoma, Md., were treated as follows: Eight hundred grams of each were treated with 2,000 c. c. of a 2 per cent sodium hydrate solution for twenty-four hours, with frequent shaking; after standing, 1,000 c. c. of the supernatant clear extract was treated with a slight excess of acetic acid and filtered. The filtrate was shaken out twice with ether and the ether allowed to evaporate on the surface of a small quantity of water, the water boiled and filtered, and the filtrate cooled. The character of any crystals which formed and the approximate amount was observed. From four of the soils examined there was obtained crystalline material having the same general appearance and properties as that obtained by this method from the Takoma soil as described above. The amount of this material obtained from 1,000 c. c. of the original extract was then dissolved in water and made up to 1,000 c. c. with distilled water and used as a culture medium for wheat seedlings. Dilutions of this stronger solution with one and with nine parts of pure distilled water were also used. The results obtained were in direct relation to the amount of crystalline material, the solution containing the greatest portion being the most harmful. The results obtained with one of the soils, that from Tennessee, are shown in Plate III, figure 2.

The soil from which, by this treatment, the most material was obtained and which furnished the most injurious medium was from Tennessee, a soil which had been in cultivation fifteen years, for the most part in cotton. This soil is classified as Clarksville silt loam, and although light colored, contains 3.26 per cent organic matter and 0.16 per cent nitrogen. The surface soil (which was collected) is a gray silt loam 6 inches deep. The subsoil to a depth of 3 feet is yellow silt loam, having a close, compact structure. The field is in a large area of this type, the Clarksville silt loam, occupying the broad, nearly level top of a ridge. There were a few apple trees in the field, but the sample was taken at some distance from any of them. The yields have been light. On an area about 50 feet square, from which the sample was taken, the plants were only about one-half to one-fourth as large as in other parts of the field, and matured very few bolls. Where vacancies occurred in the cotton rows, corn had been planted. The same difference existed in the corn as in the cotton. Near where the sample was taken the stalks were small, with a yellow color, and had failed to form good ears. In other parts of the field the corn had a good color and average-sized ears had been produced. The east half of the field contains 20 apple trees, set five years ago. One tree stands about 30 feet from where the sample was taken and is smaller than the trees farther away, thus agreeing with the growth of the cotton and the corn in different parts of the field.

A water extract of this soil was a poor medium for the growth of wheat seedlings and was improved by treatment with carbon black.

Having, then, a soil unproductive in the field and in the laboratory, and yielding by simple treatment a crystalline body injurious to plant growth, the foundation was laid for the isolation of a harmful soil compound in sufficient quantity to determine its identity and study its properties. Large quantities of this soil were treated by the method already mentioned, extraction with 2 per cent sodium hydrate solution, acidifying with acetic acid, filtering from the humus precipitate, shaking out the acid filtrate with ether, and crystallizing the water-soluble portion of the ether extract from water. By this treatment, extracting each portion of the soil twice, the body described was obtained in a fairly pure condition in amounts of 0.05 gram per kilo of soil, which is 50 parts per million, or 200 pounds per acre to the depth of 1 foot. The quantity actually present in the soil must of course be much larger, for when all is said, the methods of extraction are very crude and far from quantitative, and the amount obtained in crystalline form does not even represent the amount extracted. It is of course impossible to say what relation exists between the amount extracted and the amount present, except that the amount present is much the greater, perhaps even several times as great. This same body has been obtained by extraction with sodium carbonate instead of hydrate, though the extraction is not so profitable.

PROPERTIES OF THE ISOLATED COMPOUND.

The properties of this compound, some of which have already been noted, are:

Slight solubility in cold water, more ready solubility in hot, ready solubility in alcohol and ether. It crystallizes in radiating clusters or concretions and when pure in very small plates or leaflets, which are generally arranged in starlike groups, as shown in the photomicrograph in Plate II, figure 1. The melting point is 98° to 99° C.

Calcium and barium salts are readily formed by decomposition of the corresponding carbonates. These are little soluble in cold water, but quite readily so in hot water. The barium salt crystallizes in somewhat characteristic circular concretions of radiating structure, as shown in the photomicrograph in Plate II, figure 2. The silver salt is amorphous and quite insoluble in water.

IDENTIFICATION AS DIHYDROXYSTEARIC ACID.

All the properties of this compound agree with those of dihydroxystearic acid prepared from elaidic acid. Elementary analyses of the preparation from the soil gave the following figures:

	No. 1 found.	No. 2 found.	Calculated for $C_{18}H_{36}O_4$.
Carbon	67.5	68.0	68.3
Hydrogen	12.2	11.7	11.4
Oxygen	20.3	20.3	20.3

Analysis of the silver salt gave the following figures:

	Found.	Calculated for $C_{18}H_{35}AgO_4$.
Silver	25.77	25.53

The melting point of the soil compound remained unchanged when this was mixed with dihydroxystearic acid prepared from elaidic acid.

These figures, together with the correspondence noted between the properties of the body obtained from the soil and those of dihydroxystearic acid from elaidic acid, are sufficient to establish the identity of the soil compound as dihydroxystearic acid.

DIHYDROXYSTEARIC ACID AND RELATED COMPOUNDS.

There are four isomeric dihydroxystearic acids known, three being laboratory products. The one found in the soil is that obtained in the laboratory by the oxidation of elaidic acid and described by Saytzeff.[a] This acid can easily be prepared, starting with oleic acid. If oleic acid be treated for a few minutes at a low temperature with nitrous oxide generated in any convenient way, say by the action of nitric acid on arsenic trioxide, it is changed to the isomeric elaidic acid. This, after washing with water and recrystallizing from ether or alcohol, melts at 45° to 47° C. If this elaidic acid be dissolved in a dilute solution of potassium hydrate and treated with potassium permanganate, it is oxidized, dihydroxystearic acid being one of the products. The yield obtained in this way is low, the dihydroxystearic acid first formed being easily subject to further oxidation, pelargonic and azelaic, and finally oxalic acids being formed. Edmed[b] in studying the oxidation products of oleic and elaidic acids obtained from the latter by this treatment with alkaline permanganate, dihydroxystearic acid, 33 per cent; pelargonic acid, 13 to 14 per cent; azelaic acid, 26 per cent; and oxalic acid, 15 to 20 per cent. The dihydroxystearic acid formed from elaidic acid is much more easily oxidized than the isomeric acid obtained by oxidation of oleic acid, and this has been explained by the juxtaposition of the hydroxyl groups in the former, as shown in the structural formulas:

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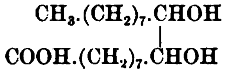
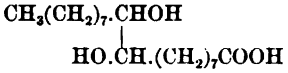
[a] Jour. prakt. Chem., **33**, 300 (1886); **50**, 76 (1894).

[b] Jour. Chem. Soc., **73**, 627 (1898).



$$\begin{array}{l} CH_3.(CH_2)_7.CHOH \\ COOH.(CH_2)_7.CHOH \end{array}$$

Dihydroxystearic acid, m. p. 99°, from elaidic acid.



$$\begin{array}{l} CH_3(CH_2)_7.CHOH \\ HO.CH.(CH_2)_7COOH \end{array}$$

Dihydroxystearic acid, m. p. 134°, from oleic acid.

The known dihydroxystearic acids other than that obtained by the oxidation of elaidic acid and found in soils are that obtained by the oxidation of oleic acid already mentioned, melting at 134° C.; one obtained from isoleic acid melting at 79° C., and a natural product found in castor oil melting at 140° to 141° C., and described by Juillard [a] and Meyer.[b] Besides the differences in melting points noted, these acids show quite important differences in their behavior toward solvents, but all agree in being little soluble in cold water. They are all monobasic acids, forming well-defined salts.

PRESENCE OF OTHER BODIES.

In describing the method used in isolating dihydroxystearic acid from the soil, mention was made of a resinous body which was present in the ether extract and which was separated from the dihydroxystearic acid after evaporation of the ether by filtration of the hot solution. This resinous material, which at the temperature of boiling water is a brown oil, becomes at room temperature a thick viscous mass. It is not soluble in water or dilute acids. In dilute alkalies it forms a slimy emulsion and dissolves readily in alcohol and ether. So far no crystalline body has been obtained from this material, nor has it been possible to make any crystalline derivatives. No characteristic color or other reactions have been noted, and it is not known whether it is a simple body or a mixture. Elementary analysis gave the following figures: Carbon, 63.84 per cent; hydrogen, 9.65 per cent.

It is very insoluble in water and when wholly free from dihydroxystearic acid it does not impart any harmful properties to distilled water, using wheat seedlings.

POSSIBLE ORIGIN OF DIHYDROXYSTEARIC ACID.

Concerning the possible origin of dihydroxystearic acid in the soil, it might not be amiss to state briefly some of the results obtained, although no definite conclusion can as yet be drawn. Among the soils containing this compound was the Takoma soil, from which picoline carboxylic acid had also been isolated. This soil was found to contain dihydroxystearic acid in almost as large amount as that from Tennessee. This Takoma soil seems to be an extremely good medium for the growth of fungi, and it was noted that the rootlets of the oak trees on this ground were infested with mold. This growth was at times so abundant that in digging up the small roots and shaking free of soil, the attached mold mycelia furnished as much material as the roots themselves. A quantity of these roots with mold attached was washed free of adhering soil and treated just as the soil had been in the isolation of dihydroxystearic acid. There was obtained in this way a small quantity of crystalline material having the appearance and properties of the dihydroxystearic acid isolated from the soil. The crystalline form, melting point, solubility, formation, and appearance of barium salt all corresponded with those of the body isolated from the soil, and there is little or no doubt of their identity. Similar oak roots from another locality where they were not infested with mold were treated in the same way, but no indication whatever was obtained of the presence of dihydroxystearic acid or any other crystalline body by this method. It would seem to be a fair conclusion from this that mold can form dihydroxystearic acid from material associated with oak roots, and that in this case, at least, the dihydroxystearic acid found in the soil may have been formed in this way. As to what material furnishes the foundation for this formation of dihydroxystearic acid by fungi, whether it be root excretions or root tissue or cells, it is possible at present to theorize only, and such discussion does not come within the scope of this paper. It may, however, not be out of place to mention that the conditions existing in nature in this case are similar to those shown in the laboratory to lead to the formation of dihydroxystearic acid. Oleic acid as part of the complex molecules of fats and readily decomposed lecithins is present in all living parts of plants; nitrous acid, by which oleic acid is changed to elaidic acid, is constantly being formed in soils, either as a product of denitrification or as one of the stages in nitrification; and, finally, there are oxidizing agents—the air, enzymes in living roots, and microorganisms.

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[a] Bul. Soc. Chim., **13**, 238 (1895).

[b] Arch. Pharm., **235**, 184 (1897).

SEPARATION OF OTHER ORGANIC COMPOUNDS FROM SOILS.

In the course of the examination of other soils for the presence of the compounds already described there have been obtained a number of bodies, some of which are undoubtedly mixtures, while others are evidently single, definite compounds. Two of these latter have been sufficiently studied to be mentioned here. The soil from which these bodies were obtained was from North Dakota, the Marshall clay, a black soil similar to the chernozen of Russia, containing 10.6 per cent organic matter and 0.51 per cent nitrogen.

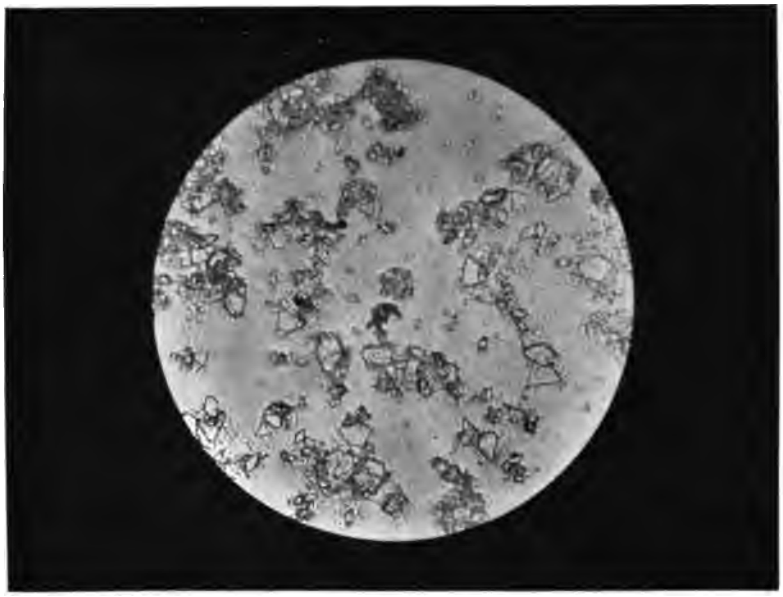

FIG. 1.—CRYSTALS OF AGROSTEROL OBTAINED FROM SOILS.

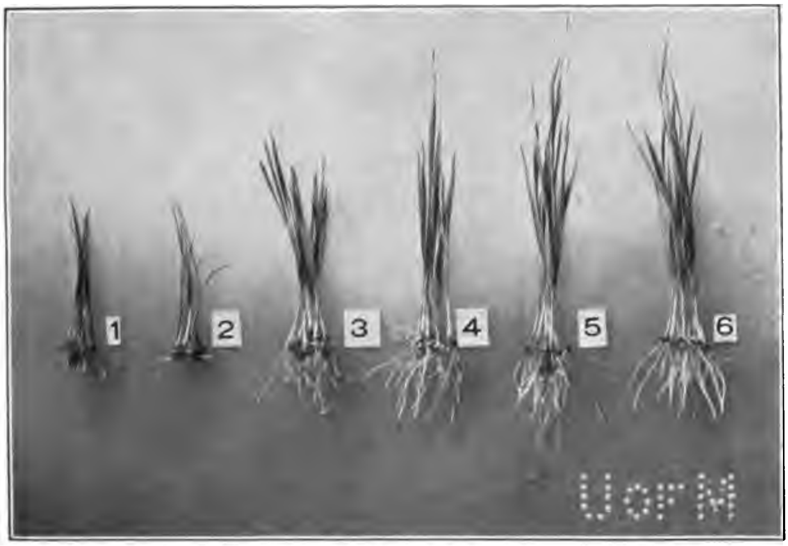

FIG. 2.—WHEAT SEEDLINGS GROWN IN EXTRACT OBTAINED IN THE METHOD FOR ISOLATING DIHYDROXYSTEARIC ACID FROM SOILS.

[1 and 2, undiluted extract; 3 and 4, one part extract, one part distilled water; 5 and 6, one part extract, nine parts distilled water.]

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ISOLATION OF A WAXLIKE BODY; AGROCERIC ACID.

When this soil is treated with hot 95 per cent alcohol and filtered while hot, there is obtained a greenish-brown extract, from which on cooling a yellowish microcrystalline precipitate separates. If the soil be treated with successive portions of hot alcohol until the extract is no longer colored, the extracts combined, concentrated to a smaller volume, and allowed to cool, this precipitate can be obtained in considerable quantity. Two hundred and fifty parts per million of this substance have been obtained from this soil in this way, equivalent to 1,000 pounds per acre-foot.

The precipitate so obtained was washed with cold alcohol, redissolved in hot alcohol, and on cooling from this solution it crystallized fairly free of color. Thus obtained this crystalline body is evidently a mixture, since the melting point is quite variable as influenced by variations in the method, such as the concentration of the original alcoholic extract, extent of washing, etc. This variation in melting point extends from 70° to 90° C. If this mixture be thoroughly dried and washed with cold ether it is separated into two portions. The ether-soluble portion crystallizes on evaporation of the ether in minute leaflets which melt at 72° to 73° C. and solidify after melting at 67° C. It is little soluble in cold alcohol, readily in hot, the solution so obtained being acid to litmus. It separates from alcoholic solution on cooling in a powdery microcrystalline form.

On adding an alcoholic solution of lead acetate to the solution of this body in hot alcohol a precipitate containing lead is formed which after washing with cold alcohol and drying melts at 109° to 110° C.

The physical and chemical properties of this compound place it among the fatty acids found either free or combined in waxes both of vegetable and animal origin.

Elementary analysis gave the following figures:

	No. 1.	No. 2.
Carbon	73.2	73.40
Hydrogen	12.2	12.19
Oxygen	14.6	14.51

The only compound which corresponds with this percentage composition is that of a hypothetical acid, the lactone of which was found and described by Strucke[a] in carnauba wax.

This acid, $C_{21}H_{42}O_3$, would have the composition—

	Per cent.
Carbon	73.7
Hydrogen	12.3
Oxygen	14.0

and the figures obtained for the compound from the soil agree with these within the limits of experimental error.

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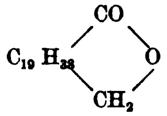
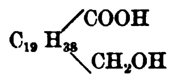
[a] Ann. Chem., **223**, 312 (1884).

Strucke isolated from carnauba wax and described a body to which he ascribed the formula



the lactone of an acid



$$C_{19}H_{38}<^{COOH}_{CH_2OH}$$

which is the one referred to above and which has not been described or isolated. Whether this compound isolated from the soil is the same as the acid corresponding to the lactone isolated from the carnauba wax can only be determined by further investigation. The compound from the soil, which will be designated as agroceric acid, is almost insoluble in water and does not impart any harmful properties to distilled water when wheat seedlings are grown, although it is not impossible that other plants may be affected differently.

PRESENCE OF OTHER WAXLIKE BODIES.

The portion of the original precipitate from the alcohol extract insoluble in cold ether is evidently a mixture of bodies. The melting point of this mixture varies from 100° to 110° C. and it contains from 3 to 7 per cent of ash, mostly alumina. Elementary analyses corrected for ash have given carbon, 74 to 77 per cent; hydrogen, 12 to 13 per cent. It is evident from its physical properties and composition that this body is a mixture of higher acids, salts of such acids, and probably higher alcohols such as make up natural waxes. This mixture, like the ether-soluble portion, is almost insoluble in water and does not form a solution harmful to wheat seedlings.

ISOLATION OF A COMPOUND OF THE CHOLESTEROL GROUP; AGROSTEROL.

When the hot alcoholic extract of the soil obtained as described above is concentrated, cooled, and separated from the precipitate of agroceric acid and other compounds the filtrate is a dark greenish-brown solution which on evaporation leaves a thick, somewhat resinous material. On washing this residue with cold ether there is left a yellowish waxlike body, the nature of which has not been investigated. The ether solution, which carries with it nearly all of the color of the original extract, on spontaneous evaporation of the ether leaves a resinous material similar to that obtained from the alcoholic solution. On treating this residue with cold absolute alcohol the coloring matter goes into solution and there is left a nearly white microcrystalline substance. This body melts at 237° C. and the melting point remains constant after recrystallizing from alcohol, ether, and chloroform. It crystallizes from ether in fine needles arranged in radiating clusters, from alcohol, if a little water is present, in very thin plates of characteristic appearance, very similar to those of phytosterol. These crystals are shown in the photomicrograph in Plate III, figure 1. The compound is almost insoluble in water; difficultly soluble in cold alcohol, readily in hot, and readily soluble in ether and chloroform. It is unchanged on heating with alcoholic potash and can be obtained from the residue of the original alcoholic extract of the soil by treating this residue with alcoholic potash, evaporating to dryness, and extracting the dry residue with ether. The crystalline appearance and general properties of this body suggest a higher alcohol of the cholesterol group.

The color reactions ordinarily used to identify and distinguish members of this group when applied to this body gave the following results: Liebermann's "cholesterol reaction," which is the only one giving positive results with all the more commonly known members of the cholesterol group, gives the characteristic violet color with the compound obtained from the soil. This reaction consists in dissolving the substance in a small amount of chloroform, adding acetic anhydride, and then a drop of strong sulphuric acid, when a violet color is produced.

The other reactions ordinarily used in distinguishing compounds of this group gave no results with the soil compound. For instance, cholesterol when dissolved in chloroform and shaken with an equal volume of sulphuric acid (sp. gr. 1.76) gives a blood-red coloration in the chloroform layer. With the soil compound the coloration was light yellow. Again, when cholesterol is evaporated with strong hydrochloric acid containing 10 per cent of ferric chloride a violet-colored residue is left. With the soil compound no coloration is produced.

There have been quite a number of compounds described and named which seem to belong to this group of cyclic alcohols known as the cholesterol group and placed by Beilstein under the general formula $C_nH_{2n-8}O$. Most of these bodies are optically active and are found in fats and waxes, either free or combined. The combination is frequently one with fatty acids, the cholesterol in this case playing the same part that glycerol does in glycerides; cholesterol, however, and others of the group so far as known having only one alcohol or hydroxyl group.

Knowledge of the chemistry of this group is rather meager, cholesterol itself being the best known.

The compounds which have been described and placed in this group, together with their sources and some of their properties, are as follows: Cholesterol, $C_{26}H_{44}O+H_2O$, found in animal fats and in olive oil, melts at 148° C. Phytosterol, $C_{26}H_{44}O+H_2O$ "vegetable cholesterol," found in vegetable fats and waxes, melts at 132° C.

Isocholesterol, $C_{26}H_{44}O$, found in some animal fats, melts at 137° C., does not react with chloroform and sulphuric acid. Sitosterol, $C_{27}H_{44}O+H_2O$, in plant fats, melts at 137.5° C. Paraphytosterol, $C_{24}H_{40}O+H_2O$, in the seed coat of *Phaseolus vulgaris*, melting at 149° to 150° C. Paracholesterol, $C_{26}H_{44}O+H_2O$, found in slime mold, melts at 134° C. Caulosterol, found in etiolated yellow lupines, melts at 158° to 159° C. Parasitosterol, $C_{27}H_{44}O$, found in the embryo of wheat, melts at 127.5° C. Homocholesterol, $C_{28}H_{48}O$, found in Dalmatian insect powder (*Chrysanthemum cinerariæfolium*), melts at 183° C. Ergosterol, $C_{26}H_{40}O+H_2O$, found in ergot, melts at 154° C. Anthesterol, $C_{28}H_{48}O$, found in *Anthemis nobilis*, melts at 221° to 223° C. Arnesterol, $C_{28}H_{46}O$, in *Arnica montana*, melts at 249° to 250° C. Many of these bodies have as yet very doubtful standing as definite organic compounds, and much investigation will yet be necessary before the standing of these less-known bodies is assured, or the relationship between them is understood.

The composition of the compound obtained from the soil was found to agree very closely with the formula $C_{26}H_{44}O$. The analysis was made with material dried at 100° C. and was as follows:

	Found.	Calculated for $C_{26}H_{44}O$.
Carbon	83. 6	83. 8
Hydrogen	11. 5	11. 8
Oxygen	4. 9	4. 4

In the compound isolated from the soil, as described above, we have, no doubt, a member of the cholesterol group. Its method of preparation, physical and chemical properties, so far as ascertained, crystalline appearance, and the cholesterol reaction are all evidence of this, and point to the existence in the soil of a compound of the cholesterol group. The cholesterol substance obtained from the soil does not correspond in melting point with any substance of this group so far described. For this compound, isolated from a soil, having the chemical properties and general appearance of substances of the cholesterol group, but differing in melting point from any of the members of this group so far described, the generic name *agrosterol* is suggested in harmony with the nomenclature of this group.

With regard to the origin of this compound in the soil, at least two possibilities present themselves: It will be seen that several members of the cholesterol group are so far as known found only in single species of plants. It may be that agrosterol is characteristic of some plant grown on this soil, and that on the decay of plants of this species it has survived the action of enzymes, fungi, and bacteria and remained in the soil as an unchanged plant residue. Since, however, the presence of a substance of this group is shown by Liebermann's reaction above mentioned in several soils from widely separated localities with different native vegetation and cropping, it would seem that this suggestion has not much weight. To make this conclusive it would be necessary to show that the substances from different soils giving Liebermann's reaction are really identical, since the reaction is only a class reaction and not specific for agrosterol or any other member of the cholesterol group.

On the other hand, it is within the range of possibility that agrosterol may be formed from some other substance through the agency of micro-organisms or chemical oxidation. The fact that Lifschütz [a] has shown that a cholesterol substance can be formed by the oxidation of oleic acid emphasizes this possibility. The fact that paracholesterol mentioned above is found in slime molds further supports the suggestion that agrosterol may be formed by micro-organisms.

CULTURE TESTS WITH THE ISOLATED COMPOUNDS.

In the study of soil fertility from the point of view stated in the first part of this paper, the first and immediate interest concerning any organic compound isolated from or proven present in a soil is with regard to the possible effect of such compound on plants. While it is probably true that every organic compound in the soil which is at all soluble is to some extent a factor influencing plant growth either favorably or unfavorably, and that before there can be any true science of agricultural chemistry the chemistry of the organic soil material, harmless as well as injurious, must be known, it is evident that at this stage the interest of the investigator, as well as of the practical agriculturist, centers around the injurious organic soil compounds. Once the identity of a soil compound is established, it can usually be prepared artificially in quantity sufficient for an extended study of its effects on plants, both alone and as modified by other soil compounds or added chemicals, fertilizers, etc., an investigation which can not but furnish much of scientific interest and practical value.

Anything like the complete knowledge of the organic matter of soils or even one soil can be arrived at only after long research, research in a field as yet almost unknown and one presenting many difficulties incident to ignorance of matter under investigation and inadequacy of available methods. Such research will follow as the natural result of the demonstration of the presence of inhibiting organic compounds in soils in the most positive and practical manner by isolating such bodies so that they can be seen, handled, and experimented with.

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[a] Zeitsch. physiol. Chem., **55,** 1 (1908).

In determining the properties of bodies isolated from soils, wheat seedlings have been used as an indicator in the manner described in former bulletins.[a] While wheat seedlings only have been used in these tests, it is not impossible that other plants may show inhibited growth where the wheat is unaffected, and vice versa, as was found to be the case in the experiment with plant succession already mentioned, in which harmful effects were noted when wheat followed wheat or oats, but wheat following corn or cowpeas was either unaffected or else benefited. In carrying out the tests, wheat seedlings three or four days old of uniform size were grown in solutions of the substances tested, control cultures of similar seedlings in pure distilled water being carried on at the same time. The transpiration and green weight of plants at the end of the period of growth, generally ten or twelve days, together with observations made from day to day on the appearance of the roots and tops furnished the data from which the conclusion as to inhibition was drawn.

EFFECT OF PICOLINE CARBOXYLIC ACID AND RELATED COMPOUNDS.

The method by which picoline carboxylic acid was isolated from soils was essentially the precipitation of the acid as either the lead or silver salt from a neutral solution of a portion of the soil organic matter. The amount obtained from the soil by this method was very small. For this reason, and more particularly to meet the objection that any observed injury might be due to minute traces of lead or silver incident to the method of preparation, the effect of this compound was tested with the artifically prepared body. The method of preparing this, which has already been stated, is in outline the treatment of pyruvic acid in alcoholic solution with dry ammonia gas, precipitation of uvitonic acid with sulphuric acid and splitting of this into picoline carboxylic acid and carbon dioxide on heating. The yield, however, is small.

The following figures give the results obtained with wheat seedlings grown for ten days in solutions of different strengths of artificial picoline carboxylic acid.

Effect of picoline carboxylic acid on wheat seedlings.

Solutions.	Relative transpiration.	Relative green weight.
Control in distilled water	100	100
Picoline carboxylic acid, 1 p. p. m	140	95
Same, 10 p. p. m	105	101
Same, 50 p. p. m	107	98
Same, 100 p. p. m	85	89
Same, 200 p. p. m	55	70

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[a] Buls. Nos. 23, 28, 36, 40, 47, Bureau of Soils, U. S. Dept. Agr.

It is seen from the figures above, substantiated by the results of other series, that this soil constituent is harmful to wheat seedlings and in low concentrations is a stimulant, an effect which is, however, characteristic of small doses of poisons when applied to plants. In the solutions containing 100 and 200 parts per million in addition to the decreased transpiration and green weight of plants the roots showed the abnormal appearance characteristic of the presence of an injurious compound, little growth with root tips first darkened, then club-shaped, or hooked. However, since this body does not show marked injurious properties in solutions containing 50 parts per million and so far as can be determined occurs in the bad soil extract from the soil examined in less amount, it does not seem likely to explain by its presence the full effect of the injurious properties of the extract from the soil in which it was found. While this effect, as will be shown, is undoubtedly due to the presence of the more harmful dihydroxystearic acid in this particular soil, nevertheless it was thought to be of interest to study in this regard several bodies closely related to picoline carboxylic acid.

Uvitonic acid, from which picoline carboxylic acid is formed simply by heating to the melting point and which differs from it only by CO_2, is so closely related that it was thought desirable to test its effect even though there was no evidence of its presence in the soil. The result of such a test with wheat seedlings grown for twelve days in solutions of different strengths of uvitonic acid is shown by the following figures:

Effect of uvitonic acid on wheat seedlings.

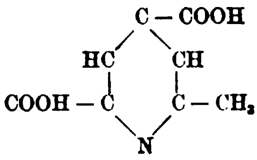
Solutions.	Relative transpiration.	Relative green weight.
Control in distilled water	100	100
Uvitonic acid, 1 p. p. m	95	107
Same, 5 p. p. m	88	116
Same, 10 p. p. m	87	108
Same, 50 p. p. m	39	78
Same, 100 p. p. m	20	68
Same, 200 p. p. m	35	Dead.

The plants growing in concentrations of 200 parts per million were dead when the test was terminated, and the transpiration of this set is higher, owing to this death of the plants, as dying plants frequently show increased transpiration.

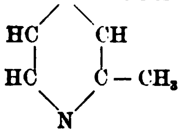
Uvitonic acid, it is evident, is quite harmful to wheat seedlings, much more so than the nearly related picoline carboxylic acid. It is also reported to be strongly antiseptic, which is again an indication of highly injurious properties for higher plants.

The relative effect of these two compounds brings up the question of the relation of chemical constitution to inhibitory effect on plant growth. Uvitonic acid and picoline carboxylic acid are related as shown by the structural formulas

Uvitonic acid.



Picoline carboxylic acid.



the former differing from the latter by CO_2, which on heating splits off from the carboxyl. Uvitonic acid, as shown, is a dicarboxylic acid, and the greater inhibition would seem to be associated with the presence of the second carboxyl group. However, all the carboxylic acids of pyridine and its homologues having one, two, and three carboxyls are weak acids. They form salts with bases in the usual way, but have also the power of forming salts with mineral acids by direct addition; for instance, the hydrochlorate, by the addition of hydrochloric acid. It is only in the higher members of this group, for instance, where all the H atoms are replaced by carboxyl, that the acid properties predominate and the power to form salts with mineral acids is lost. The whole question is one for future investigation, the data at present available furnishing little more than suggestions of possible explanations. It may be said, however, that the harmfulness of these compounds does not seem to be due to hydrogen ions.

Other related compounds, which may have a possible soil interest in this connection, have already been studied with the following results:[a]

Pyridine (C_5H_5N) forms the nucleus upon which are built many of the alkaloids. It is obtained chiefly from coal tar, but may also be obtained from a number of alkaloids, such as nicotine, trigonelline, sparteine, and cinchonine, when these are highly heated, treated with alkalies, or distilled with zinc dust. Pyridine is a colorless liquid of penetrating odor and basic properties. Laurent[b] found that a 1 per cent solution of pyridine was harmful to the fungi which he studied. It has been observed by Falkenburg[c] that the vapor of pyridine and some of its homologues is poisonous to bacteria.

In the experiments with wheat seedlings it was found that although pyridine, in a concentration of 1,000 parts per million, did not kill wheat plants in nine days it was nevertheless very injurious, especially to the growth of the green parts of the plants. In a concentration as low as 50 parts per million the growth of the tops was inhibited and the leaf tips turned brown. In the lower concentrations there was no stimulation of growth.

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[a] Bul. No. 47, Bureau of Soils, U. S. Dept. Agr., 1907.

[b] Ann. Soc. Belge Micr., **14,** 29 (1890).

[c] Czapek, Biochemie der Pflanzen, II, 926.

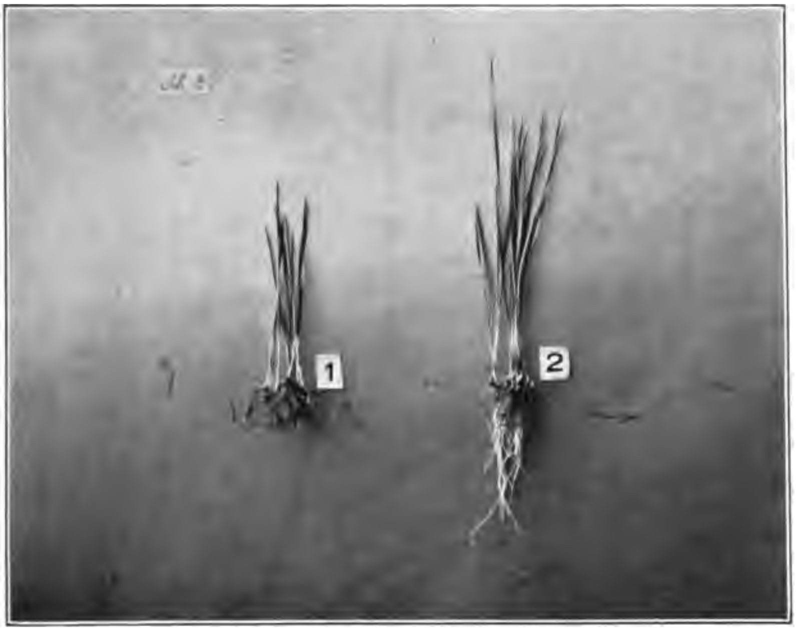

FIG. 1.—WHEAT SEEDLINGS SHOWING THE EFFECT OF DIHYDROXYSTEARIC ACID FROM SOILS.

[1, saturated solution of dihydroxystearic acid; 2, control in pure distilled water.]

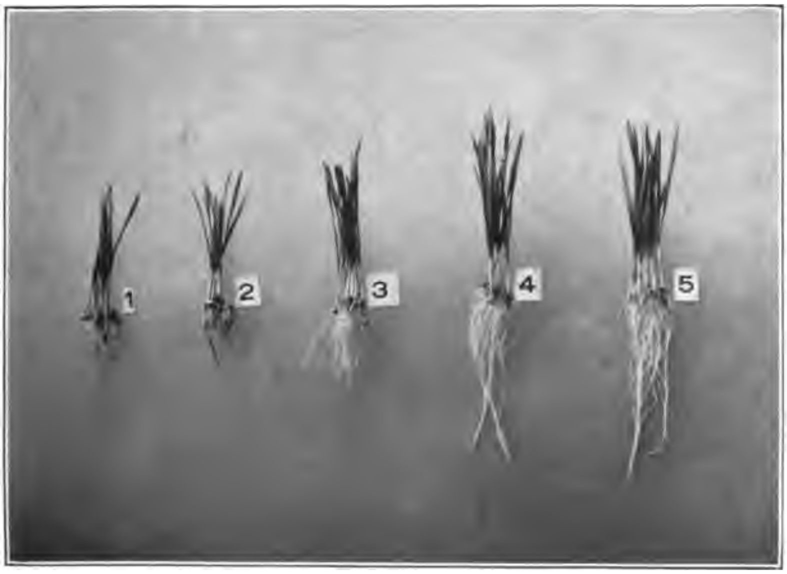

FIG. 2.—WHEAT SEEDLINGS GROWN IN SOLUTIONS OF DIHYDROXYSTEARIC ACID FROM SOILS.

[1, solution of dihydroxystearic acid, 200 parts per million; 2, 100 parts; 3, 50 parts; 4, 20 parts; 5, control in pure distilled water.]

Picoline ($C_5H_4N.CH_3$) or methyl pyridine was harmful to wheat plants, but only killed in the concentrations of 1,000 parts per million, and did not cause injury below 500 parts per million. The injury seemed to be manifested by the tops more than by the roots, thus resembling the action of pyridine.

Piperidine ($C_5H_{11}N$), or hexahydropyridine, is known to occur in nature, for example, in the pepper plant, and forms the nucleus of many alkaloids. Solutions of piperidine killed and injured at a lower concentration than either pyridine or picoline. A sample of piperidine that was neutralized with acetic acid proved to be more toxic than the strongly alkaline piperidine itself. Piperidine seems to injure the roots more severely than the tops.

Quinoline (C_9H_7N) has a genetic relationship with pyridine and forms the nucleus of many alkaloids found in plants belonging to the families Rubiaceæ and Loganiaceæ. Falkenburg[a] found that quinoline was harmful to bacteria in a concentration of 2,000 parts per million. Quinoline killed wheat plants at a concentration of 500 parts per million. So low a concentration as 5 parts per million affected them injuriously in six days. None of the lower concentrations caused stimulation of growth.

While picoline carboxylic acid may not be an important factor in the infertility of the Takoma soil, the fact that it has been found in other soils in larger quantities, its moderately harmful effect, and its close relationship to other pyridine compounds still more harmful, places it among organic soil compounds to be considered and sought for in the general study of unproductive soils.

EFFECT OF DIHYDROXYSTEARIC ACID.

The dihydroxystearic acid isolated from the soil was readily obtained in quantity sufficient for cultural experiments, and as its method of preparation was such that it could easily be obtained free of any reagents which might have an injurious effect, the body obtained from the soil was used in testing the effect of this compound. As a preliminary test a saturated solution of dihydroxystearic acid, which was found to contain approximately 200 parts per million at room temperature, was used as a culture solution for the growth of wheat seedlings. The result is shown in Plate IV, figure 1. Ten days' growth of the seedlings in this solution gave a green weight of plants 52.5 as compared with 100 for the same number of seedlings in distilled water for the same time. The water transpired by the plants growing in dihydroxystearic acid solution was 12.3 against 100 transpired by the plants growing in distilled water.

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[a] Czapek, Biochemie der Pflanzen, II, 926.

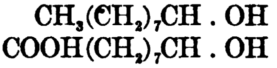
The harmful effect of this compound in not very high concentration being thus established, culture sets comprising several concentrations were then grown, the results of the ten days' growth being as follows:

Effect of dihydroxystearic acid on wheat seedlings.

Solutions.	Relative transpiration.	Relative green weight.
Dihydroxystearic acid 200 p. p. m	20	54
Same, 100 p. p. m	24	53
Same, 50 p. p. m	56	78
Same, 20 p. p. m	75	87
Control in pure distilled water	100	100

These results are illustrated in Plate IV, figure 2. The effect of this body, it will be noted, is as great in a concentration of 100 parts per million as in a concentration of 200 parts per million, which is approximately a saturated solution, and is marked even when the concentration is as low as 20 parts per million.

Artificial dihydroxystearic acid prepared as described from elaidic acid, as well as the isomeric dihydroxystearic acid formed on the oxidation of oleic acid, gave in concentration of 200 parts per million practically the same results, very little transpiration, green weight about half of that in the control solutions, and death of the plants in twelve or fifteen days. Other than this there has been no study of the effect of compounds related to the dihydroxystearic acid found in the soil.

Dihydroxystearic acid is, as may be inferred from its power to decompose carbonates, a much stronger acid than picoline carboxylic acid, and as represented by the formula  $\begin{array}{c}CH_3(CH_2)_7CH\,.\,OH\\COOH(CH_2)_7CH\,.\,OH\end{array}$ partakes also of an alcoholic nature. Whether the harmful effect of this compound is due to the combination of alcohol and acid characters, the so-called hydroxyacid structure, is of course not known. As has already been stated the whole question of the relation between effect on plant growth and composition and constitution is one which will be thoroughly understood only after long investigation. It may be well to note, however, in discussing the effect of a body of an acid constitution like dihydroxystearic acid that the data at present available is sufficient to prove that toxicity is not necessarily connected with the acid character or the presence of hydrogen ions. It is well known that an acid which is little dissociated in solution may be much more harmful than another which is dissociated to a much greater extent. For this as well as other reasons based on observations on the effect of organic compounds many of those who have studied this question hold that the harmful effect of organic compounds is in many cases associated with the structure of the molecule rather than due entirely to dissociation products.

Preliminary investigations have shown that some of the combinations of dihydroxystearic acid with bases are as harmful as the acid itself, although much less soluble. It was found that cultures in the calcium and potassium salts of dihydroxystearic acid gave greater green weights and greater transpiration than cultures in distilled water, while the iron and alumina salts, although less soluble than the acid, gave a growth and transpiration almost as low as solutions of the acid itself. The iron and alumina salts, because the least soluble, are perhaps the ones most likely to be present in soils. It would seem, then, that the injurious effect of this body when found in the soil may not be confined to that produced slowly during its formation, but that it may be stored up in a little-soluble but very harmful form.

SUMMARY.

Previous investigations have indicated that soils may be infertile or "exhausted" because of the presence in them of organic compounds injurious to plants.

The present paper deals with the isolation and identification of some of the inhibitory or injurious compounds in such infertile soils. It is almost self-evident that where such bodies give rise to infertile soils there can be intelligent scientific treatment of such soils only when the nature and properties of these bodies are known. The isolation and identification of these bodies is the first step in the attainment of this knowledge.

In approaching this problem, which is an exceedingly complex one, it was found necessary to review briefly the knowledge of the origin of the organic matter in the soil. This review shows that the soil organic matter arises through the decay of organic compounds of vegetable and animal origin; that among these compounds are many of well-known composition and constitution which get into the soil and may even persist for a time, and that many compounds which are formed from these in the process of decay are likewise well established as definite chemical compounds.

When the effect of these compounds which are known to get into the soil or to be formed in the soil is considered, it is found that many of them have been shown to be harmful to plants, some even when in very small amounts. On the other hand, it is not yet possible to trace any general relation between the harmful properties and the chemical composition or constitution, and consequently it is not possible to determine the effect of any compound on plants except by experiment.

In addition to known products of vegetable and animal origin and their products of decay, it is possible that still other compounds are produced and exist in the soil about which there is no knowledge, not even of a speculative kind. In view of these facts, it was found necessary to consider briefly the present knowledge of soil organic matter in general. It was found that although the organic matter in soils is an important ingredient, amounting in most cases to many tons per acre, almost nothing is known of the chemical nature of this material.

The difficulties, then, in attempting to isolate harmful organic compounds from infertile soils are due to ignorance of what compounds are harmful to plants and what are not, and also to lack of knowledge of the chemical nature of the organic matter of the soil and consequent lack of methods for dealing with such material.

The first crystalline organic compound isolated from a soil was a nitrogenous body, picoline carboxylic acid, which was obtained by a process which had its starting point in a solution of a portion of the organic matter in sodium hydrate solution. This body is a definite crystalline compound with very faint acid properties and has also the power of acting as a base toward strong acids. Along with the isolation of this compound there were obtained indications of the presence in the same soil of other bodies, some of which are related to it.

From the same and another soil by a modification of the same method another organic compound was obtained. This compound, dihydroxystearic acid, is nonnitrogenous and is in no way related to the nitrogenous body first isolated. Dihydroxystearic acid, like picoline carboxylic acid, is a well-defined crystalline chemical compound heretofore known only as a laboratory product.

The properties of these two organic compounds were tested by the effect of their solutions on wheat seedlings. Picoline carboxylic acid was found to be harmful in concentrations of 100 parts per million, and like many poisons had a stimulating effect when present in small quantities. Dihydroxystearic acid was injurious in all concentrations tested and ultimately caused death of the plants in concentrations of 100 parts per million.

Two other crystalline organic compounds previously undescribed in the literature were isolated from a soil. One of these, which has been named agroceric acid, is a member of the waxy acids; the other, which has been named agrosterol, belongs to the cholesterol group of bodies. Neither of these substances appear to be harmful to wheat and are of interest in the study of soil fertility chiefly with regard to their possible connection with the generation or destruction of injurious or beneficial compounds, although it is not impossible that they may be themselves harmful to plants other than that tested.

Apart from the purely scientific interest attached to the isolation from soil of any definite organic compound, the work here stated furnishes a simple tangible proof of the presence of injurious organic compounds in soils and should lay the foundation of the rational study and remedy of unfavorable conditions in such unproductive or so-called "exhausted" soils.

In the present bulletin there are described four organic compounds isolated from soils, all well-defined crystalline bodies, one of which is quite injurious, one slightly harmful but related to much more harmful compounds, and two that are not harmful so far as the wheat seedlings used in the tests are concerned, although, as pointed out above, other plants may be quite differently affected by these substances.

In addition to these, there have been isolated a number of other well-defined bodies, likewise crystalline. These various soil compounds are being studied and as far as possible their nature and properties will be determined and the results given in future publications.

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Issued December 31, 1908.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS—BULLETIN No. 54.
MILTON WHITNEY, Chief.

THE MINERAL COMPOSITION OF SOIL PARTICLES.

BY

G. H. FAILYER, J. G. SMITH, AND H. R. WADE.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1908.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., July 23, 1908.

Sir: I have the honor to transmit the manuscript of an article entitled The Mineral Composition of Soil Particles, by G. H. Failyer, J. G. Smith, and H. R. Wade, and to recommend that it be published as Bulletin No. 54 of the Bureau of Soils.

Very respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

It is now generally understood that the mineral components of soils fall into two general classes. The first class comprises the common rock-forming minerals. It is generally the case, however, that a soil appears to be much more complex and to contain many more different minerals than any given rock. This is due in part to the fact that in the rock a certain few minerals which characterize that particular rock predominate to such an extent as to mask the other minerals which may be present. It is also due in part to the fact that the transportation of soil material from point to point, often to great distances, by wind and water and other agencies, produces a very complex mineral mixture, so that in almost any soil all or nearly all of the common rock-forming minerals can be found. It is very probable also that many minerals form in the soil. The various mineral fragments can be found to a greater or less extent through all the various sized soil particles, but in general, as might be anticipated from their origin, the finer the particles of the soil the more complex is the mineral mixture.

The second class of mineral components in the soil consists of decomposition products derived from the first class by the action of water and other weathering agencies of one kind or another. It is common knowledge that of these substances the silica, as quartz, tends to accumulate in the coarser grades of soil particles and ferruginous material in the finer grades. The distribution of the other products is not so obvious, although of the first importance for both theoretical and practical handling of soil problems.

The existing literature on this subject is meager and unsatisfactory. The tedious and difficult analytical operations involved have undoubtedly deterred investigators hitherto; but the importance of the subject in itself and as a connecting link in the larger problem of the mineral chemistry of the soil, which is being investigated by this Bureau, has led Mr. Failyer, with Messrs. Smith and Wade, to study the chemical composition of the soil separates of a number of soils, covering all the important agricultural areas of the United States. The mineralogical composition of these same separates is still under investigation.

The conclusions summarized at the end of the present bulletin may be taken safely as applying to soils generally, and mark another positive step forward in our knowledge of soils.

Frank K. Cameron.

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THE MINERAL COMPOSITION OF SOIL PARTICLES.

INTRODUCTION.

As is well known, soils are made up of mineral particles of many different sizes, and the relative proportions of the different sized particles have a most important influence on the physical properties of the soil and its adaptability to the growth of various kinds of crops. Therefore, in the mapping of soils by the Bureau, mechanical analyses of many type samples are made. By sedimentation, assisted by a centrifuge, soils are separated into arbitrary mechanical components called clay, silt, and sand. The latter is separated by sifting into five grades. As used by the Bureau, clay comprehends particles having a diameter of 0.005 mm. or less; silt includes particles whose diameters range from 0.005 to 0.05 mm.; very fine sand, particles from 0.05 to 0.1 mm.; fine sand 0.1 to 0.25 mm.; medium sand, 0.25 to 0.5 mm.; coarse sand, 0.5 to 1 mm.; very coarse sand, 1 to 2 mm.

It is a matter of interest and importance to know how these separates compare in their content of the important mineral plant-food constituents. For instance, whether phosphorus, potassium, and calcium be uniformly distributed through the sand, the silt, and the clay, or whether they be concentrated in one or more of these separates; and whether different classes and types of soils differ in this respect.

Another matter of interest is the influence of the manner of the formation of the soil and of climate upon the distribution of the several mineral nutrients. The past history of the soil greatly affects its mechanical and mineralogical composition. How it will affect the distribution of the plant-food constituents is not always obvious.

For some time investigators have recognized that the groups of various sized particles of a soil may differ in chemical composition. Considerable attention has been given to certain phases of the subject; but it has not as a whole received the detailed study that it deserves. Much of the analytical work that has been done upon the mechanical separates of soils has been by treatment with some conventional strength of hydrochloric acid. Such work is a study of solution and not of ultimate composition.

Apparently Loughridge[a] was the first to make any study of the chemical composition of the mechanical elements of a soil. By means of Hilgard's churn elutriator he prepared mechanical separates of a loam upland subsoil from Mississippi. The separates were extracted by five days' digestion in hydrocloric acid of 1.115 specific gravity and the solution analyzed. Larger proportions of potash, magnesia, iron, alumina, and silica were found in the extract of the finer portions than in that of the coarser. The lime was irregular and the soda and sulphuric acid somewhat uncertain.

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[a] Am. Jour. Sci., 7, 17 (1874).

Orth[a] made mechanical separations of samples of a soil taken at four depths. These samples consisted of the surface soil to a depth of about 8 inches—loamy sand; a layer of subsoil about 16 inches thick—loamy sand; a 16-inch layer of loam below the preceding, and a thick layer of marly loam under all of these. Chemical analyses, by decomposition with hydrofluoric acid, were made of each of these samples and of the particles of each under 0.01 mm. in diameter. The whole soil of each layer contained a greater percentage of silica than did the part less than 0.01 mm., while the latter contained a higher percentage of potash, lime, magnesia, soda, iron, alumina, and phosphoric acid. Orth does not make these comparisons, but a recalculation of his tabulated figures makes the comparison possible. It should be observed that this is not a direct comparison of the composition of the coarse with that of the fine particles. The whole soil is compared with its finest part. Indirectly, of course, a comparison is made of the coarser with the finer portions of this one soil and its subsoil.

Schneider[b] studied a residual soil from the Rockland Ridge, near The Dalles, on the Columbia River, Washington. The rock whose disintegration formed the soil is said to be an augite andesite, its principal constituents being "plagioclase, augite, apatite, magnetite, undifferentiated glass."

The soil was subjected to mechanical analysis by Hilgard's well-known method. For purposes of analysis, four groups were made of the sediments prepared from the fine earth—the part less than 0.6 mm. diameter. One group included particles of diameters between 0.5 and 0.1 mm.; another, particles between 0.1 and 0.01 mm.; another, those between 0.01 and 0.001 mm., and the last portion, particles less than 0.001 mm. This last fraction was called "clay."

Both fusion and acid digestion methods were used in analyzing these sediments, but as indicated in Table I, not all the analyses were carried to completion.

Table I gives Schneider's results calculated to water-free and organic-matter-free substance. The dimensions of the fractions are derived from Hilgard's "Table of diameters and hydraulic values of sediments."[c]

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[a] Ber., **15**, 3028 (1882).

[b] Am. Jour. Sci., **36**, 236 (1888).

[c] Am. Jour. Sci., **6**, 337 (1873).

The author points out that the percentages of " alkalis and alkaline earths extracted by the hydrochloric acid decrease in the fractions almost proportionately to the decrease of total percentages obtained in the analysis by fusion."

From an inspection of Table I it is seen that the phosphoric acid and the magnesia are irregularly distributed among the sediments; that the lime decreases with the size of the particles; and that the potash, so far as given, increases as the particles decrease in size.

TABLE I.—*Partial composition of the separates of a soil analyzed by Schneider.*

Grade of material.	By fusion.			By acid digestion.			
	CaO	MgO	K_2O	P_2O_5	CaO	MgO	K_2O
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Particles 0.5 to 0.1 mm	6.57	2.60	1.54	0.14	3.02	1.06	0.32
Particles 0.1 to 0.01 mm	....	....	....	.18	2.60	.82	.88
Particles 0.01 to 0.001 mm	3.32	1.86	1.90	.46	2.23	1.56	.66
"Clay," less than 0.001 mm	.51	1.93	....	.14	.21	1.43	....

In studying the changes in composition when rocks weather to soils Merrill[a] has analyzed a soil and the " silt " separated from it. Under silt are included particles 0.1 mm. and less in diameter. This silt contained larger percentages of potash, lime, and magnesia than did the soil.

R. Sachsse[b] analyzed the fine earth of five soils and also the portions of these soils carried over by a stream of water of 0.2 mm. velocity. A comparison of the tabulated results shows great irregularity in the distribution of the elements. The lime, potash, and alumina are proportionately more abundant in the very fine particles than in the soil as a whole. The proportion of iron, magnesia, and soda is greater in the finer parts of some of the soils; in others the reverse is true. The phosphoric acid in the portions carried by the 0.2 mm. stream is not given. In this case, as before, the whole soil is compared with one of its parts.

Meyer[c] likewise compared the composition of the whole soil with that of its finer parts. Twenty-six soils differing much in physical character were used in his work. For analysis and comparison, three samples were prepared from each soil. One consisted of the whole soil, excluding gravel above 5 mm. in diameter. It was pulverized in a mortar to pass through a 0.5 mm. sieve, for treatment with acid as described below. Another sample was the " fine earth." It was obtained from a portion of the original soil by sifting, the part passing through a 0.24 mm. sieve being taken for analysis. The third sample was the clay or dust (staub). It was separated from another portion of the original soil by sifting, and consisted of particles not greater than 0.11 mm. in diameter. Since the finer grades of soil particles are found in all three samples thus prepared and the coarser ones are not, any differences in composition of the samples must be due to differences between the fine and the coarse particles. These samples were digested in hydrochloric acid for three hours at 100° C. and the extract analyzed. With very few exceptions he found greater percentages of lime, magnesia, iron and alumina, and phosphoric and sulphuric acids, in the extracts of the " fine earth " than in those of the whole soil, and greater percentages of these substances in the extracts of the " dust " than in those of the " fine earth." No determinations were made of the potash in the samples. Since only the substances dissolved by the acid were determined, this is more a solubility study than one of composition.

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[a] Bul. Geol. Soc. Am., 6, 323 (1895).

[b] Chem. Centr.-Blatt., 66, 1, 752 (1895). The original publication (Geologische Spezialkarte der Königreichs Sachsen, Sektion Lommatzsch-Leuben) is not accessible to us.

[c] Landw. Jahrb., 29, 913 (1900).

Tolman,[a] working on two soils from the arid region, found a greater degree of solubility in the finer particles, but the acid (hydrocholric acid of 1.115 sp. gr.) extracted notable amounts from all of the separates, even those of 2 mm. diameter. A higher percentage of potash, soda, magnesia, iron, alumina, and phosphoric acid was found in the solutions of the finer portions. The lime varied, but was an approximately constant constituent of the separates. He compared his results with those obtained by Loughridge and found, as might be anticipated, that much greater proportions of the soluble substances occur in the coarser grains of the arid soils than in those of like size in the humid soil.

Headden,[b] working upon a granitic soil on the station grounds, took a sample 10 inches deep and separated the fine earth (the portion passing through a sieve of 1 millimeter mesh) by beaker elutriation into 6 components. Complete chemical analyses were made of the " fine sand," particles 0.25 to 0.05 mm. in diameter, the " silt," 0.05 to 0.01 mm., the " dust," 0.01 to 0.001 mm., and the " clay," less than 0.001 mm. It is pointed out that the separates differ decidedly in composition, and that " there is an accumulation of potash in the finer portions of the soil, and a diminution of the silicic acid."

Westermann[c] investigated the relations of the " clay " (ler) content of certain Danish soils to their content of the several plant food constituents. He made mechanical analyses of 100 soils from eighteen counties well distributed over Denmark. Eighteen of these soils, varying in clay content from high to low, were digested forty-eight hours at 19° C. in 30 per cent hydrochloric acid, and the solutions analyzed. He finds no constant relation between the content of phosphoric or sulphuric acids extracted and of "clay;" the relation between the content of potash and of " clay " is close; there is a general similarity in the content of " clay " and of lime, magnesia, and iron, but there are important individual departures from the rule.

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[a] Rept. Cal. Agr. Expt. Sta., 1898-1901, Part I, p. 33.

[b] Bul. 65, Colo, Agr. Exp. Sta. (1901), p. 19.

[c] Underslogelser over Typer af danlske Jorder, Copenhagen, 1902.

Bagger[a] studied the relation of the soluble potash content of soils to the impalpable matter they contain, using results of other workers as well as some of his own. In some of the published results of analyses he finds that soils containing the more clayey substances are richer in soluble potash; in others the reverse is true. Bagger himself examined eight soils of known history. A micaceous sandy soil containing little " clay " (abgeschlammte teile) was rich in potash soluble in concentrated hydrochloric acid, while heavy loams contained much " clay " and little potash. His general conclusion from his study of soils is that the potash content of the soil bears no definite relation to its mechanical composition, thus combating a view held by several agricultural writers. Potash is the only constituent considered by this author. He compares the potash extracted from the soils as a whole with that from the finer particles, and does not determine the potash in the mechanical separates themselves.

Schloesing[b] selected four soils that varied from very sandy to very clayey, and separated these into their mechanical components by a method of sedimentation, which is given. These separates were boiled with hydrochloric acid and the iron and phosphoric acid in the extracts determined. In each of the soils the iron and the phosphoric acid increased as the size of the physical elements decreased. The iron and the phosphoric acid contained in the undissolved mineral grains would not be determined by this treatment. Schloesing[c] also compares the separates of two subsoils as to their content of carbon. The soils above the subsoils are rich in organic matter. One of the subsoils is highly calcareous, the other nearly free from lime. Schloesing found that the finer portions of these subsoils are the richer in carbon. He is of the opinion that soil grains are coated with the various substances that have gone into solution in soils and have separated out again. Since the surface of small particles is greater compared to their mass than is the case with larger ones, these coatings would form a higher percentage of the finer separates, even if they be of the same thickness.

Rudzinski,[d] in the course of experiments in the growth of plants in the mechanical elements of soils, prepared separates of a clayey chernozem (black earth), a peaty clay, and a podzol soil (an ashy soil composed largely of very fine sand). He concludes from his chemical examination of the separates that the content of potash and of phosphoric acid in the mechanical elements of the soils investigated decrease with the increase of their size, and that the like separates from soils of like geological origin even are unlike in their chemical composition.

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[a] Inaug. Diss., Albertus-Universitat, Königsberg, 1902.

[b] Compt. rend., **134,** 631 (1902).

[c] Compt. rend., **135,** 601 (1902).

[d] Izv. Moscow Selsk. Khoz. Inst. (Ann. Inst. Agron., Moscow.), IX, No. 2, p. 172 (1903). (Expt. Sta. Rec. XVI, 345, 1904.)

Mazurenko[a] made mechanical analyses of two strikingly different soils, a loess and a podzol. The data show that in the separates of both soils the silica decreased and the other elements increased as the size of the particles decreased.

Dumont[b] compares the distribution of potash among the separates of two soils about equally rich in this substance, but very different as to origin and manner of formation. One was a fine-grained soil from an experimental field at Grignon, the other a coarse, sandy granitic soil from Creuse. They were separated into different sized particles by the method of Schloesing, the separates decomposed by hydrofluoric acid, and analyzed by usual methods.

Table II shows the percentage of potash in the separates, the potash of each separate expressed as percentage of the whole soil, and the percentage distribution of the potash of the soil among the separates.

TABLE II.—*Potash content of soil separates according to Dumont.*

Grade of particles.	Potash, per cent of separate.		Potash, per cent of soil.		Per cent of potash of soil in separate.	
	Soil of Grignon.	Soil of Creuse.	Soil of Grignon.	Soil of Creuse.	Soil of Grignon.	Soil of Creuse.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Coarse sand	0.864	1.33	0.148	0.605	16.55	70.93
Fine sand	.992	.58	.588	.225	65.78	26.37
Clay	.940	.51	.158	.023	17.67	2.70
	....	....	.894	.853	....	....

It is obvious that although these soils contain about the same proportion of potassium, the element is very differently distributed in their mechanical components. The separates of the Grignon soils are about equally rich in potash, while the sand of the soil of Creuse is nearly three times as rich as the clay. As pointed out by Dumont, five-sixths of the total potash of one soil is contained in its finer particles, whereas in the other, on the contrary, seven-tenths of the potash of the soil is in the coarse sand.

Hall[c] prepared separates of the Rothamsted soils by sedimentation. Composites were prepared by mixing the sediments of like grade derived from the several soils. The partial composition of these mixed sediments, as given by Hall, shows that the percentage of silica decreases and that of the alumina and the iron increases as the size of the sediments decreases—an observation confirmed by work in this laboratory for soils in general.

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[a] Inaug. Diss., Munich; Abs. in Zhur. Opuitn. Agron. (Jour. Expt. Landw.), V, No. 1, p. 73 (1904). (Expt. Sta. Rec. XVI, 344, 1904.)

[b] Compt. rend., **188**, 215 (1904).

[c] Jour. Chem. Soc., **85**, 950 (1904).

Puchner,[a] in an article on the distribution of nutrients in the separates of the soil, describes his work upon three soils differing widely in physical character and in geological origin.

Soil No. 1 was a heavy loam; No. 2, a silty soil (loessial); No. 3, a coarse sandy soil from gneiss. These soils were resolved into their mechanical components, four divisions being made of the particles less than 0.25 mm. in diameter. Complete analyses were made of these finer separates. The medium and coarse sands not being analyzed, no comparison of the composition of these with the finer portions can be made.

The composition of the finer separates of the three soils is given in Table III. Table IV gives the content of the elements in the several separates calculated to percentages of the soil.

TABLE III.—*Composition of the mechanical separates analyzed by Puchner.*

[The figures express percentages of the separates.]

Mineral constituent.	1. Heavy loam.				2. Loamy loess soil.				3. Coarse sandy gneiss soil.			
	Coarse dust, 0.25 to 0.01 mm.	Medium dust, 0.01 to 0.005 mm.	Fine dust, 0.005 to 0.0015 mm.	"Clay" (Schlamm) 0.0015 to 0 mm.	Coarse dust, 0.25 to 0.01 mm.	Medium dust, 0.01 to 0.005 mm.	Fine dust, 0.005 to 0.0015 mm.	"Clay" (Schlamm) 0.0015 to 0 mm.	Coarse dust, 0.25 to 0.01 mm.	Medium dust, 0.01 to 0.005 mm.	Fine dust, 0.005 to 0.0015 mm.	"Clay" (Schlamm) 0.0015 to 0 mm.
CaO	Tr.	Tr.	0.04	Tr.	7.23	6.28	4.09	3.39	2.55	1.18	2.23	2.44
MgO	0.39	1.42	1.08	0.15	2.41	2.08	1.45	1.19	0.31	.42	.81	.32
K_2O	4.14	1.02	.12	.01	.81	.70	.67	.56	.08	.05	.04	.06
Na_2O	2.85	2.29	2.01	1.18	3.25	3.05	3.02	2.48	3.05	2.94	1.43	1.22
Fe_2O_3	2.49	5.14	8.95	12.60	3.77	4.98	6.86	9.85	5.38	7.20	9.23	11.11
Al_2O_3	1.63	15.20	20.48	27.76	7.28	14.20	19.41	29.97	18.71	24.20	30.21	32.42
Mn_3O_4	Tr.	.70	1.10	3.65	1.54	1.88	1.94	2.79	1.56	1.74	2.48	3.10
P_2O_5	.03	.08	.08	.19	.15	.12	.17	.03	.06	.03	.05	.04
SiO_2	87.51	72.08	63.22	51.01	71.45	63.95	59.40	50.23	58.00	61.70	52.22	46.54
Humus	74	1.48	2.00	3.32	.11	.76	.89	1.97	.23	.59	1.40	2.81

TABLE IV.—*The P_2O_5, CaO, MgO, and K_2O, in the separates analyzed by Puchner, calculated to percentages of the total soil.*

Mineral constituent.	1. Heavy loam.				2. Loamy loess soil.				2. Coarse sandy gneiss soil.			
	Coarse dust, 0.25 to 0.01 mm.	Medium dust, 0.01 to 0.005 mm.	Fine dust, 0.005 to 0.0015 mm.	"Clay" (Schlamm) 0.0015 to 0 mm.	Coarse dust, 0.25 to 0.01 mm.	Medium dust, 0.01 to 0.005 mm.	Fine dust, 0.005 to 0.0015 mm.	"Clay" (Schlamm) 0.0015 to 0 mm.	Coarse dust, 0.25 to 0.01 mm.	Medium dust, 0.01 to 0.005 mm.	Fine dust, 0.005 to 0.0015 mm.	"Clay" (Schlamm) 0.0015 to 0 mm.
P_2O_5	0.02	0.03	Tr.	0.02	0.10	0.03	Tr.	Tr.	0.01	0.01	Tr.	Tr.
CaO	Tr.	Tr.	Tr.	Tr.	4.67	1.63	0.04	0.23	.43	.27	0.11	0.13
MgO	.20	.46	Tr.	.01	1.56	.54	.01	.08	.05	.10	.04	.02
K_2O	2.08	.33	Tr.	Tr.	.52	.18	.01	.04	.01	.01	Tr.	Tr.

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[a] Landw. Vers.-Stat. 66, 463 (1907).

From the results Puchner draws the conclusion that as the mechanical separates become finer the content of silicic acid, soda, and potash diminishes. On the contrary, that of alumina, iron, manganese, and humus increases. The content of lime, magnesia, and phosphoric acid in the separates is irregular.

Alway and McDale[a] conclude from their study of the distribution of carbonates in the till of the second steppe of the northern Great Plains region that the carbonates are chiefly present in the grains of intermediate size; i. e., the silt particles running from 0.05 to 0.005 mm. in diameter.

Clerk, Gortner, and Vail,[b] working upon a sample of bowlder clay representing the upper 6 feet, made four mechanical fractions—sand, 1.0 to 0.05 mm.; coarse silt, 0.05 to 0.016 mm.; fine silt, 0.016 to 0.005 mm.; clay, smaller than 0.005 mm. These fractions were analyzed chemically by digestion in hydrochloric acid and the determination of the dissolved substances.

In this soil the lime, as carbonate for most part, formed the highest percentage in the silts and least in the clay; the iron, alumina, soda, potash, and phosphoric acid were in greater proportions in the finer fractions; the silts contained the highest percentage of magnesia and the clay the next.

In addition to the investigations mentioned above, numerous chemical and mechanical analyses of the same soil have been made. From the published results of this work one could make comparisons of the total percentages of the several chemical elements in a soil with its percentage content of any particular mechanical component. For example, it could be determined for each soil whether a high content of calcium goes with a high content of sand, of silt, or of clay; but since the investigators themselves did not study these relations, such purely physical and chemical analyses of soils have not been included in a historical review of the literature of the chemical composition of the mechanical separates of soils.

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[a] Am. Chem. Jour., **37**, 275 (1907).

[b] Am. Chem. Jour., **39**, 163 (1908).

NOTE.—Since the manuscript for this bulletin went to the printer a report of additional work along the line of this investigation has come to hand:

Atterberg (Landw. Vers.-Stat., **69**, 102, 1908), working upon a glacial sand from Kulltorp, made complete analyses of the six groups into which he separated the portion between 0.5 mm. and 0.005 mm. diameter. In the table of results given by them the aluminum is a nearly constant constituent; there is an increase in the percentage of the iron and the calcium as the size of the particles decreases except in the finest portion—that between 0.01 and 0.005 mm.—in which these elements decrease. The potassium and the sodium decrease as the particles become smaller.

SELECTION OF SOIL SAMPLES.

Our extensive collection of soils from important and well-marked soil types enables us to select samples fully representative of the soils of the country. Accordingly, agricultural soils of known character were selected so as to include those from various geographical sections and from a number of soil provinces. Thus we have taken soils from the Coastal Plains, the Piedmont region, glacial soils, nonglaciated soils of the interior, and those of the arid region, the list comprising 27 soil types. These soil types are fully described in the reports of the Field Operations of the Bureau of Soils and in the Soil Survey Field Book, but since these publications may not be easily accessible to readers of this bulletin, the several types analyzed are described briefly in the proper place. The samples taken for analysis are from the surface soil, but the field characteristics of a type, as well as its agricultural value, are often largely dependent upon the subsoil. The subsoils, therefore, often serve to differentiate one soil type from another. The characteristics of the subsoil should therefore be considered an essential part of the description of a soil type. In view of these facts it is obvious that definite conclusions regarding the productiveness of a soil can not be made from a study of the surface soil alone.

Two hundred gram composite samples of the several soil types were separated into the three grades—sand, silt, and clay. In making these separations the whole of the water was poured into the clay dish and evaporated to dryness. Thus any material which dissolved in the repeated treatment of the soil with water was carried into the clay, and this fact must be considered in comparing the results of the analyses of the separates.

The important mineral nutrients only were determined; that is, phosphorus, potassium, calcium, and magnesium. A complete analysis of the soil separates, so far as these constituents are concerned, was made by fusion methods, so that the total content was obtained, and not simply that which would have been extracted by treatment with acid of some conventional concentration.

In the tables giving the results of the analyses the figures are the percentages of the respective substances in the ignited separates, and thus free from organic matter and water. The aim has been to learn the composition of the strictly mineral matter of the soils. It seems safe to assert, however, that were calculations made on the oven-dried soils there would merely be changes in percentages and no material ones in the order of these, so that conclusions based upon them would be consistent with those based upon the mineral matter, as here given.

SOILS OF THE COASTAL PLAINS.

The Coastal Plains are made up of unconsolidated gravels, sands, silts, and clays derived in most part from the erosion of the Piedmont Plateau and other inland areas. These materials were mainly deposited on the then ocean floor and have been brought to their present level by the elevation of the land areas.

The character of the soils of the Coastal Plains in a broad way, therefore, depends upon that of the rocks and soils of the Piedmont Plateau, but they are modified by deposits from other sources. Thus in the northern portions glacial material is mixed to some extent with the débris of the disintegrated and more or less decomposed rocks of the plateau. In some instances, streams which rise far inland and drain limestone regions have brought materials not common to most of the Coastal Plains soils. While the soils of this region present many diversities among themselves, due to special circumstances affecting their deposition or subsequent history, they all differ much from the parent rock and have been subjected to excessive weathering and leaching.

In studying soils and the results of their analyses, it should be fully recognized that the soil as now found is a distinct product or entity. Simple crushed rock represents no very important agricultural soil. Plants will grow in certain rock powders if compounds of nitrogen be present, but such a " soil " is nowhere found in extensive areas, except possibly as subsoils, and some subsoils were once real surface soils. Unconsolidated rock material should be called rock and not soil, unless it has been subjected to the processes called weathering, with all the numerous changes implied by the term, including those produced by high and low forms of animal and plant life. The soil depends primarily, in the sense of first cause, upon the rock or the rocks from which it originated. As a first step in soil making, the rocks may disintegrate or be crushed to sand or dust. Mechanical agencies may separate the pulverized rocks into groups according to size of particles and deposit them as beds of sand, silt, or clay; or these may remain together, giving rise to loams. Solution and hydration and other chemical processes may effect changes which in some cases leave many of the original mineral grains; in others, the changes may be so profound that few of the original minerals other than quartz remain. The latter extreme condition is less common than is generally supposed, the original minerals, though undoubtedly present, being in so finely divided a form as to be difficultly recognized. Absorptions taking place in soils and other facts make it probable that new minerals similar, if not identical, to those existing in rocks are formed in soils in minute particles. A soil will then be best understood when all the factors which have operated to produce it are known; that is, when the whole history of the formation of the soil is known. This must often be inferred from the present character of the soil and the geological history of the region. From these considerations it might be expected that soils formed in one general way, as the Coastal Plains soils have been, would constitute a class by themselves and differ in important particulars from those that have had an entirely different history, as glacial soils, for instance. This subject will be referred to again in comparing groups of soils after the analytical data have been given.

The Coastal Plains soils are mostly light; sands and light sandy loams predominating. Those selected for our work are the Collington sandy loam from New Jersey; Norfolk sand, Norfolk loam, and Leonardtown loam from Maryland; Orangeburg sandy loam from Alabama; Crowley silt loam from Louisiana; Orangeburg fine sandy loam from Texas.

Collington sandy loam.—The sample analyzed is from the Salem area, New Jersey, surveyed in 1901. The soil is a loose, coarse, sandy loam. It is of a brown color and frequently contains considerable amounts of gravel. It has resulted from the weathering of the greensand, or glauconite, of New Jersey. The subsoil, which comes within 6 or 8 inches of the surface, is a sticky, tenacious, claylike material, yellowish or greenish in color. Owing to its relations to the greensand deposits, this type differs from the other Coastal Plains soils.

Norfolk sand.—The sample of this type analyzed is from Prince George County, Md. The area was surveyed in 1900. This is a coarse to medium orange or yellow sand, having a depth of about 10 inches. The subsoil is coarse to medium, becoming loamy at about 3 feet. It is a common type of soil in the Atlantic and Gulf Coastal Plains. The surface is level to rolling and the soil is well drained.

Norfolk loam.—The soil is from the Worcester County area, Maryland, surveyed in 1903, and was mapped as Sassafras sandy loam. This soil is a mellow brown sandy loam to a depth of about 9 inches. The subsoil to 36 inches is a medium to heavy loam, which is often underlain by fine yellow sand. In the area from which the samples were taken it has a slight elevation and is gently rolling. It is usually well drained.

Leonardtown loam.—The samples used were collected in the soil survey of St. Mary County, Md., 1900. The soil of this type consists of a yellow silty loam, fine and powdery when dry, but puddling to a plastic mass when thoroughly wet. The subsoil consists of a brittle mass of interlocking clay lenses, lumps, and fragments, separated by seams and pockets of medium to fine sand. This subsoil is as impervious as clay, owing to its peculiar shinglelike structure. It is an upland soil and is generally slightly rolling.

Orangeburg sandy loam.—Samples analyzed are from Montgomery County, Ala., surveyed in 1905. This soil, locally called "red lands," is a brown to reddish-brown light sandy loam, 4 to 15 inches deep, resting on a friable brick-red sandy clay subsoil. The surface is rolling. It is generally well drained, although there is a tendency to form a "plowsole" or "hardpan."

Crowley silt loam.—The samples used were taken from samples of soil collected in the survey of Acadia Parish, La., 1903. This type is of variable depth, but usually has a surface soil of about 16 inches. It is of a brown color when wet, but ash gray when dry. It is composed of fine sand and silt, with sufficient clay to render it rather impervious. If stirred when wet it puddles somewhat. This soil is underlain by a clay of mottled brown and yellow color, with brick-red streaks and blotches. The subsoil is highly impervious and the surface level, so that the soil has very poor drainage. The samples analyzed are from level prairies in southern Louisiana.

Orangeburg fine sandy loam.—The samples used came from the Nacogdoches area, Texas, survey of 1903. This soil varies in color, being red, brown, or gray. It is a light sandy loam, generally carrying iron concretions. The subsoil is a red, friable, sandy clay. The type occupies the upland and has good natural drainage.

The percentage of the several mechanical constituents—sand, silt, and clay—contained in the soils is given in Table V. The results of the chemical analyses of the mechanical separates for phosphoric acid, lime, magnesia, and potash are given in Tables VI and VII. In Table VI the figures express percentages of the separates; in Table VII the percentages are calculated on the whole soil, so that the figures show what percentage the constituent in a separate is of the soil of which the separate is a part.

An inspection of Table VI shows that the elements determined—phosphorus, calcium, magnesium, and potassium—are more abundant in the finer particles of these old soils—old in the sense of having passed through and being the result of all the stages of soil formation.

As shown in Table VII, the coarse particles often contain absolutely more of the elements than the finer portions, but this, of course, is due to the presence in the soil of a much greater percentage of these large particles.

TABLE V.—*Mechanical composition of the Coastal Plains soils.*

Soil type and location.	2 to 0.05 mm. (sand).	0.05 to 0.005 mm. (silt).	0.005 to 0 mm. (clay).
	Per cent.	*Per cent.*	*Per cent.*
Collington sandy loam, New Jersey	78.5	14	6.5
Norfolk sand, Maryland	85.5	10	4
Norfolk loam, Maryland	64.5	25.5	9
Leonardtown loam, Maryland	29.5	55	15
Orangeburg sandy loam, Alabama	71	16	12
Crowley silt loam, Louisiana	15	59	26
Orangeburg fine sandy loam, Texas	69	22	9

TABLE VI.—*Partial chemical composition of the separates of the Coastal Plains soils.*

Soil type and location.	P_2O_5.			CaO.			MgO.			K_2O.		
	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Collington sandy loam, New Jersey	0.01	0.09	0.18	0.06	0.30	0.40	0.18	0.22	0.66	0.49	1.86	2.25
Norfolk sand, Maryland	.01	.10	.94	.07	.27	.98	.19	.11	.48	.33	2.38	2.35
Norfolk loam, Maryland	.01	.06	.42	.09	.23	1.30	.02	.19	.48	.44	1.49	1.39
Leonardtown loam, Maryland	.01	.02	.03	.04	.08	.13	.07	.25	.87	.56	1.20	1.88
Orangeburg sandy loam, Alabama	.01	.21	.21	.03	.19	.24	.01	.11	.14	.05	.96	1.48
Crowley silt loam, Louisiana	.08	.08	.32	.11	.16	.29	.09	.05	.97	.51	.80	1.47
Orangeburg fine sandy loam, Texas	.07	.12	.36	.10	.09	.54	.04	.06	.70	.21	.66	1.50

TABLE VII.—*The content of the separates of the Coastal Plains soils calculated on the whole soil.*

Soil type and location.	P_2O_5.			CaO.			MgO.			K_2O.		
	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Collington sandy loam, New Jersey	0.01	0.01	0.01	0.05	0.04	0.03	0.06	0.03	0.04	0.38	0.26	0.15
Norfolk sand, Maryland	.01	.01	.04	.06	.03	.04	.16	.01	.02	.28	.23	.09
Norfolk loam, Maryland	.01	.02	.04	.06	.06	.12	.01	.05	.04	.28	.38	.18
Leonardtown loam, Maryland	.01	.01	.01	.01	.04	.02	.02	.14	.13	.17	.66	.28
Orangeburg sandy loam, Alabama	.01	.03	.02	.02	.03	.03	.01	.02	.02	.04	.07	.17
Crowley silt loam, Louisiana	.01	.05	.08	.02	.10	.07	.01	.03	.25	.07	.48	.37
Orangeburg fine sandy loam, Texas	.05	.03	.03	.07	.02	.05	.03	.01	.06	.14	.15	.13

SOILS FROM CRYSTALLINE AND METAMORPHIC ROCKS.

Three soils, not of glacial origin, formed from crystalline and metamorphic rocks, were selected for this work—Chester mica loam (Maryland), Porters black loam (Virginia), and Cecil clay (North Carolina.)

Chester mica loam.—Described as Cecil mica loam in the report of the Soil Survey of Harford County, Md., 1901. This soil, as its name indicates, is characterized by a great quantity of micaceous particles. It is derived from granites, gneisses, and other micaceous rocks over which the type lies. It is strictly a residual soil and consists of a brownish loam 10 to 15 inches deep, underlain by a lighter colored, heavier loam, also containing mica. The surface varies from gently rolling to somewhat hilly.

Porters black loam.—The sample analyzed was collected in the soil survey of the Albemarle area, Virginia, 1902. The soil of this type is a loose, mellow black loam, averaging about 12 inches deep. The subsoil is slightly heavier and of a light-brown to yellowish color. In depressions and coves, where wash from the higher ground has accumulated, there is no sharp distinction between soil and subsoil, the loose black loam being several feet deep. Both soil and subsoil contain fragments of the rocks whose decomposition has formed the soil—granites, gneisses, and schists. This type occurs principally in the coves of the Blue Ridge Mountains, but is also found upon the tops and upper slopes.

Cecil clay.—The samples of this type were collected near Statesville, N. C., in the survey of that area in 1901. This type is found on uplands, gentle slopes, and rolling lands of the Piedmont Plateau. The Cecil clay is a residual soil, resulting from the disintegration of a number of rocks, differing in mineralogical characters. Granites, gneisses, schists, and other somewhat similar rocks have contributed to the formation of this type, and so thorough have been the disintegration and decomposition that the same red clay results from all. There is such a gradual change from soil to the parent rock that there is generally no sharp line between the two. The soil consists of a heavy red loam, containing many sand grains of the original minerals forming the rocks from which the soil is derived. It is shallow, averaging about 5 inches. The subsoil is a stiff, tenacious red clay to a depth of 3 or more feet. It becomes heavier at greater depths. Natural drainage is fairly good, probably due to the sand and rock fragments contained in soil and subsoil.

The mechanical composition and the results of the analyses of the separates of these soils are given in Tables VIII, IX, and X.

With few exceptions the percentage of the several mineral plant-food constituents increases as the size of the particles of the separates decreases. Chester mica loam, however, which contains many micaceous scales, shows a nearly constant percentage content of lime and magnesia in its separates, while Cecil clay shows the reverse order as to the potash content, the sand being richest in potash, the silt slightly poorer, and the clay decidedly the poorest of the three. While there are some notable exceptions, the absolute quantities are generally fairly evenly distributed in the mechanical components of these soils, as shown in Table X.

TABLE VIII.—*Mechanical composition of the residual soils formed from crystalline and metamorphic rocks.*

Soil type and location.	2 to 0.05 mm. (sand).	0.05 to 0.005 mm. (silt).	0.005 to 0 mm. (clay).
	Per cent.	*Per cent.*	*Per cent.*
Chester mica loam, Maryland	36	33	30
Porters black loam, Virginia	53	23	24
Cecil clay, North Carolina	58	17	24

TABLE IX.—*Partial chemical composition of the separates of soils formed from crystalline and metamorphic rocks.*

Soil type and location.	P_2O_5.			CaO.			MgO.			K_2O.		
	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Chester mica loam, Maryland	0.04	0.06	0.33	0.22	0.24	0.28	0.96	0.81	0.88	1.44	2.56	2.55
Porters black loam, Virginia	.15	.53	1.36	1.20	2.07	2.30	.33	1.37	2.28	1.86	3.10	5.06
Cecil clay, North Carolina	.03	.06	.32	.08	.15	.23	.16	.40	.56	1.49	1.45	.97

TABLE X.—*Content of the separates of residual soils from crystalline and metamorphic rocks, calculated on the whole soil.*

Soil type and location.	P_2O_5.			CaO.			MgO.			K_2O.		
	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Chester mica loam, Maryland	0.01	0.02	0.08	0.08	0.07	0.07	0.34	0.25	0.23	0.51	0.79	0.68
Porters black loam, Virginia	.08	.12	.33	.64	.47	.55	.17	.31	.55	.99	.70	1.21
Cecil clay, North Carolina	.02	.01	.08	.05	.03	.06	.09	.07	.13	.87	.25	.24

SOILS OF GLACIAL ORIGIN.

The group of soils of glacial origin includes soils formed from material deposited by glaciers or this material somewhat reworked by water, and also loessial soils, consisting largely of particles the size of silt, which have been carried from other glacial areas and deposited over the underlying material. The transporting agents in this case were wind and water.

The mechanical composition is given in Table XI; the results of the chemical examination are given in Tables XII and XIII, calculated as before upon the separates and the soils, respectively.

Podunk fine sandy loam.—The sample for analysis was taken from a large sample from a very sandy phase of the type found in the Connecticut Valley. The area was surveyed in 1903. This is an alluvial soil, formed by the reworking by running water of glaciated granites, gneisses, and schists. It contains an abundance of micaceous mineral particles visible to the eye. It is underlain by fine sand. The soil is of a dark-brown color and is well drained. The tobacco field from which the sample came had been heavily fertilized for years.

Miami sand.—From the Toledo area, Ohio, surveyed in 1902. The soil is a coarse to medium loose and deep yellowish sand. It is underlain by a yellow sand of about the same texture. It is level to rolling and consists of glacial material somewhat modified by wind action. It occupies elevated positions and is well drained.

Wabash loam.—Described as Miami loam in the Report of the Soil Survey of the Toledo Area, Ohio, 1902. This is a dark-brown to black soil of good depth, and containing a small proportion of the coarser grades of sand. The subsoil is a heavy brownish-yellow loam overlying a fine gravelly loam. It is a bottom land, frequently occurring as terraces. It is generally well drained. It consists of glacial drift redeposited by stream action.

Volusia silt loam.—The sample for analysis was collected in the soil survey of the Wooster area, Ohio, 1904. This soil is a gray to brown silty loam with an average depth of 8 inches. The subsoil is a light-yellow silty loam, mottled with gray in its lower portions. It has resulted in most part from the glaciation of shales. Its mechanical constituents closely resemble in size those of the soils derived from the loess, being composed largely of silt. This is doubtless due to the silt in the shales from which this soil type comes in large part.

Marshall loam.—From samples of this type collected during the survey of the Marshall area, Minnesota, 1903. The surface soil is a somewhat heavy loam from 10 to 12 inches in depth and of a dark-brown color. Under this is a stiff, sticky yellow subsoil to a depth of about 3 feet. Below this is a stiff bowlder clay, mottled yellow and gray. The type is generally rolling and well drained. Bowlders and glacial gravel occur to some extent over this soil.

Miami silt loam.—Described as Edgerton silt loam in the Report of the Soil Survey of the Janesville Area, Wisconsin, 1902. The soil is a very silty loam, light brown when wet and light gray when dry. Its depth is about 8 inches. It is underlain by several feet of stiff, yellow, silty clay that is always mottled with gray, showing poor drainage and aeration. This type originally consisted mainly of timber lands and oak openings.

Marshall silt loam.—Described as Janesville silt loam in the Report of the Janesville Area, Wisconsin, 1902. The soil is a mealy, chocolate-colored silt loam with a dark-brown tint when moist. It contains a large amount of silt and becomes somewhat sticky when wet. It is about 10 inches deep. The subsoil is a sticky, reddish-yellow silty clay, about 3 feet deep, and rests upon a glacial gravel or the disintegrating limestone of the region. The soil probably owes some of its distinguishing characteristics to the influence of this limestone.

The type is rolling and well drained. It was originally covered with the prairie grasses of the region.

Marshall black clay loam.—Samples collected in the survey of McLean County, Ill., 1903. This soil is a heavy, somewhat sticky granular clay loam, containing a large percentage of silt and organic matter It has a depth of about 18 inches. The subsoil is a mottled yellow or drab-colored sticky, silty clay. This soil type has formed where the natural drainage was poor. The surface is level. In its original condition it was wet and swampy and required thorough drainage.

Marion silt loam.—Samples from Clay County, Ill. The area was surveyed in 1902. The Marion silt loam consists of a light-brown to whitish very silty loam, containing very little organic matter. Its depth averages 12 inches. The soil cakes on drying, but breaks down into flour-like dust when pulverized. The subsoil is heavier and contains more clay. It is so impervious to water as to be locally called hardpan. The lower subsoil is a hard, silty, mottled yellow clay, often containing iron concretions. Below 4 or 5 feet more or less glacial gravel is found. The type is level or slightly rolling. The soil has very poor natural drainage, owing to the rather impervious subsoil and the level surface. While of loessial origin, this soil has been largely formed from sandstones and shales ground up by glaciers.

Shelby silt loam.—The sample analyzed was collected in the soil survey of Shelby County, Mo., 1903. The Shelby silt loam is a silty soil of medium depth and of a light-gray color when dry; dark gray when wet. It grades into a stiff, impervious silty clay, plastic and waxy when wet, friable and loamy when dry. The subsoil is a dark mottled clay. It is level or gently rolling. The original growth on this type of soil was the prairie grasses.

TABLE XI.—*Mechanical composition of the glacial soils.*

Soil type and location.	2 to 0.05 mm. (sand).	0.05 to 0.005 mm. (silt).	0.005 to 0 mm. (clay).
	Per cent.	*Per cent.*	*Per cent.*
Podunk fine sandy loam, Connecticut	80.5	18	2
Miami sand, Ohio	91.5	5.5	3.5
Wabash loam, Ohio	50.5	38	12
Volusia silt loam, Ohio	17	64	19
Marshall loam, Minnesota	48	38	13
Miami silt loam, Wisconsin	14	72	14
Marshall silt loam, Wisconsin	12	70	17
Marshall black clay loam, Illinois	21.5	57.5	20
Marion silt loam, Illinois	13	69	18
Shelby silt loam, Missouri	7	74	19

TABLE XII.—*Partial chemical composition of separates of the glacial soils.*

Soil type and location.	P_2O_5.			CaO.			MgO.			K_2O.		
	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Podunk fine sandy loam, Connecticut	0.12	0.31	3.36	2.35	1.89	6.22	1.10	1.89	3.96	0.74	3.74	4.70
Miami sand, Ohio	.21	.51	1.52	.83	2.59	2.12	.34	1.21	.75	1.89	2.44	3.98
Wabash loam, Ohio	.11	.19	.40	1.56	1.56	3.98	.42	1.07	1.74	2.24	2.90	4.18
Volusia silt loam, Ohio	.09	.09	.46	.43	.30	.43	.37	.37	1.41	2.11	2.16	2.96
Marshall loam, Minnesota	.18	.19	.37	1.63	1.53	4.02	.61	1.30	1.73	1.97	1.71	1.02
Miami silt loam, Wisconsin	.12	.19	.56	.91	.83	1.37	.57	.50	1.73	2.07	2.44	3.73
Marshall silt loam, Wisconsin	.13	.24	.52	.76	.81	1.20	.46	.75	1.68	1.78	2.41	3.32
Marshall black clay loam, Illinois	.31	.32	.56	3.17	2.50	5.53	1.26	1.29	2.79	1.99	2.39	2.54
Marion silt loam, Illinois	.05	.08	.35	.38	.51	.88	.10	.14	.99	.94	1.44	2.07
Shelby silt loam, Missouri	.19	.16	.49	.41	.44	1.14	.13	.25	1.20	1.50	1.87	2.26

TABLE XIII.—*Content of the separates of the glacial soils calculated to percentages of the whole soil.*

Soil type and location.	P_2O_5.			CaO.			MgO.			K_2O.		
	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Podunk fine sandy loam, Connecticut	0.10	0.05	0.07	1.89	0.33	0.12	0.89	0.33	0.08	0.60	0.66	0.09
Miami sand, Ohio	.19	.03	.05	.76	.14	.07	.31	.07	.03	1.73	.13	.14
Wabash loam, Ohio	.06	.07	.05	.79	.59	.48	.21	.41	.21	1.13	1.10	.50
Volusia silt loam, Ohio	.02	.06	.09	.07	.19	.08	.06	.24	.27	.36	1.38	.56
Marshall loam, Minnesota	.09	.07	.05	.78	.58	.51	.29	.49	.22	.89	.64	.13
Miami silt loam, Wisconsin	.02	.14	.08	.12	.60	.19	.08	.36	.24	.28	1.76	.52
Marshall silt loam, Wisconsin	.02	.17	.09	.09	.57	.20	.06	.52	.29	.21	1.69	.56
Marshall black clay loam, Illinois	.07	.18	.11	.68	1.44	1.11	.27	.74	.56	.43	1.37	.51
Marion silt loam, Illinois	.01	.05	.06	.05	.35	.16	.01	.10	.18	.12	1.00	.37
Shelby silt loam, Missouri	.01	.12	.09	.03	.33	.22	.01	.19	.23	.11	1.38	.43

In general, the finer separates of the soils of this group contain the greater percentages of the several elements determined. The Marshall loam and the Volusia silt loam depart most widely from this rule, but several others do not strictly conform to it. The extreme proportionate richness of the clay of the Podunk fine sandy loam may have some connection with the great quantity of fertilizers that have been applied in the growing of tobacco on the field from which the sample was taken.

As to total content of the elements in the several separates, this is generally determined by the relative quantity of the separates in the soil. Thus in the soils consisting largely of silt, a large part of the phosphorus, calcium, magnesium, and potassium is contained in the silt. In the soils consisting largely of sand, the plant-food constituents are found in greatest quantity in the sand. As shown in Table XIII, the silt of Miami silt loam and of Marshall silt loam contains much more phosphate, lime, magnesia, and potash than is contained in the sand and clay combined. The sand of the Miami sand contains more of these elements than the combined content of the silt and the clay.

SOILS DERIVED FROM LIMESTONES AND SHALES.

Five soils formed from limestones and shales without glacial agency are included in this comparison—Oswego silt loam from Kansas; Wabash silt loam, Kansas; Hagerstown loam, Tennessee; Hagerstown clay, Kentucky; Houston clay, Alabama.

Oswego silt loam.—Described as Oswego loam in the report of soil survey of Parsons area, Kansas, 1903. This soil consists of a dark gray silty loam, varying from very shallow to 10 inches deep, which grades into a stiff clay, becoming more impervious with depth. It becomes hard and compact on drying, but it is easily broken up into a mellow loam if plowed when in proper condition of moisture. This is an upland type and occupies gently rolling prairies. Owing to the topography of the country, the type has good surface drainage. The Oswego silt loam is derived from the weathering of the underlying rock, this usually being shales, with occasional interbedded layers of sandstone and limestone.

Wabash silt loam.—The sample analyzed is from Riley County, Kans. The area was surveyed in 1906. The soil varies from 12 to 24 inches in depth and consists of a dark-brown to black heavy silt loam. It is easily cultivated and readily kept in good tilth. The subsoil consists of a compact and rather heavy brown or yellowish silt loam. It occurs as long, narrow tracts in the creek valleys and along the outer edges of the river valleys. The type occupies a rather low position in stream valleys and on gentle slopes. Its surface is nearly level or gently sloping. It forms first bottoms of smaller streams and second bottoms of larger ones. It is well drained naturally. The type has been deposited by water, the surface consisting largely of material washed from the surrounding hills, which are made up of shales and limestones. This wash from the hills is continually adding to the type.

Hagerstown loam.—Sample collected in the soil survey of the Pikeville area, Tennessee, 1903. This soil consists of brown or yellowish-brown mellow loam from 9 to 12 inches deep. It is underlain by a yellow to reddish-yellow stiff loam or light clay loam, which becomes a more pronounced red with depth. Traces of chert are found in both soil and subsoil. This type was formed by the slow weathering of limestones. In this soil the weathering has been so complete and the leaching so excessive that the lime of the disintegrated stone has been largely washed from the soil. The type has a moderately rolling surface and has good surface drainage, but the subsoil is rather impervious. The underlying limestone comes near the surface in some places, owing to erosion.

Hagerstown clay.—The sample analyzed was collected in the soil survey of Scott County, Ky., 1903. This soil has a heavy texture and varies from 3 to 12 inches in depth. It is yellow or brown in color. The subsoil is a heavy yellow clay, extending to a depth of 3 or more feet. This soil type is derived from limestones and shales. These rocks offer considerable resistance to disintegration, and the soil may therefore be more thoroughly leached than would be the case were the rocks more readily decomposed. The surface is rather rough, rounded hills being dominant features. Surface washing has been great, and the soil is generally shallow, the depth depending on its position. This is a residual soil, being formed from the breaking down in place of the underlying limestones and shales.

Houston clay.—The sample is from Dallas County, Ala. The area was surveyed in 1905. Although this type is really a Coastal Plains soil in so far as its mode of occurrence is concerned, it is here grouped with the limestone soils. It has resulted from the weathering of rotten limestones or chalks of Cretaceous time. Owing to its proximity to the soft and easily broken down lime rock, this soil is highly calcareous, and often contains lime concretions, especially in the subsoil. It may be considered to be of comparatively recent origin and as a residual Coastal Plains soil. The soil is a gray, brown, or black loamy clay, 6 inches deep. This is underlain with 3 or more feet of heavy gray or mottled yellow clay. The surface is gently rolling and the drainage very good. Agriculturally the soil is lighter than would be expected from its high clay content. This may be due to flocculation by the high percentage of lime present.

Table XIV shows the mechanical composition of the soils of this group. Tables XV and XVI give the results of the chemical examinations.

TABLE XIV.—*Mechanical composition of the soils formed from limestones and shales.*

Soil type and location.	2 to 0.05 mm. (sand).	0.05 to 0.005 mm. (silt).	0.005 to 0 mm. (clay).
	Per cent.	*Per cent.*	*Per cent.*
Oswego silt loam, Kansas	25	57	18
Wabash silt loam, Kansas	13	69	18
Hagerstown loam, Tennessee	36	40	23
Hagerstown clay, Kentucky	7	48	46
Houston clay, Alabama	28.5	25.5	46.5

TABLE XV.—*Partial chemical composition of the separates of limestone and shale soils.*

Soil type and location.	P_2O_5.			CaO.			MgO.			K_2O.		
	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Oswego silt loam, Kansas	0.07	0.08	0.31	0.19	0.33	0.93	0.06	0.13	1.54	0.64	1.31	1.88
Wabash silt loam, Kansas	.05	.07	.40	.81	.88	2.67	.30	.43	2.16	2.27	2.96	3.64
Hagerstown loam, Tennessee	.04	.05	.40	.22	.26	.94	.19	.30	1.60	.12	.84	1.68
Hagerstown clay, Kentucky	.32	.28	.55	7.81	3.12	2.37	.76	.87	2.32	3.48	3.60	5.07
Houston clay, Alabama	.48	.36	.77	28.73	29.51	26.45	.87	.88	1.60	.79	1.05	1.10

TABLE XVI.—*Content of the separates of the limestone and shale soils calculated to percentages of the whole soil.*

Soil type and location.	P_2O_5.			CaO.			MgO.			K_2O.		
	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Oswego silt loam, Kansas	0.02	0.05	0.05	0.05	0.19	0.16	0.02	0.07	0.27	0.16	0.75	0.33
Wabash silt loam, Kansas	.01	.05	.07	.10	.60	.48	.04	.29	.38	.29	2.03	.65
Hagerstown loam, Tennessee	.01	.02	.09	.08	.10	.22	.07	.12	.37	.04	.34	.39
Hagerstown clay, Kentucky	.02	.13	.25	.55	1.50	1.09	.05	.42	1.07	.24	1.73	2.33
Houston clay, Alabama	.14	.09	.36	8.19	7.53	12.30	.25	.22	.74	.23	.27	.61

Excepting the lime and the phosphates in the calcareous soils, Hagerstown clay of Kentucky and Houston clay of Alabama, these limestone and shale soils follow the rule that the finer the separate the greater the percentage of the four elements determined. In the cases of high lime content there may be calcium carbonate in the form of sand as that term is here used, and quartz and other sands may be coated with carbonate of lime. In the clay soils the greatest absolute quantity of lime is contained in the clays; in the loams the silts often have greater quantity.

The Oswego silt loam and the Hagerstown loam are in marked contrast with the clays in that the latter contain larger percentages of the several elements determined, notably the potash in Hagerstown clay, the lime in Houston clay, and the phosphoric acid in both. This comparative poverty in the former is doubtless due in part to these soils being the result of more extended weathering than are the two clays, and the rocks from which they are formed differ considerably.

While the separates of any one of these shale and limestone soils can be compared among themselves, no useful comparison of one of the soils with another can be made unless the full history of the soils be considered. Some of them have come from shales with layers of interbedded limestones, others from massive limestones, and the extent of weathering and leaching has varied so that a similar soil could not result. Notwithstanding this, the plant-food constituents are concentrated in the finer separates of all these shale and limestone soils as in those of greatly different origin.

Not only are the finer separates of this group of soils richer in plant-food constituents as determined by percentage composition, but since the soils are mainly clay and silt the absolute quantities, as shown by Table XVI, are greater in these portions.

SOILS OF THE ARID REGIONS.

Two soils formed under arid conditions, or at least that have been under arid conditions for very long periods, were used in this work—one from the Fresno series and one from the Indio series.

Fresno fine sandy loam.—Described as Fresno sandy loam in the report of the soil survey of the Fresno area, California, 1900. This soil is composed largely of silt to fine sand. It is locally known as "white-ash land," from its color and its physical character. The soil has probably been derived from volcanic ash, but light-colored loams and sands have also contributed to it. The soil lies flat and works well, unless it be puddled, when water penetrates it slowly and hard clods or lumps form on drying. The lower subsoil is heavier, a blue clay being encountered at the depth of a few feet. Because of poor drainage or light rainfall this soil generally contains alkali.

Indio fine sandy loam.—Described as Fresno sandy loam in the report of the soil survey of the Indio area, California, 1903. This soil is made up of clay, silt, and the finer grades of sand. The clay is so flocculated that the soil in its field condition is lighter than the mechanical composition would indicate. The soil was mainly formed by erosion from adjacent mountains, the material being deposited in a bay or arm of the sea, but it has been greatly modified by wind action. It contains micaceous grains and minute shells. The soil ranges in depth from 2½ to 5 feet and is underlain with sandy loam or sand. The surface usually has a uniform slope and is generally well drained, but its high capillary power draws much water to the surface, causing an accumulation of alkali by its evaporation. In the lower levels the alkali is present in injurious amounts. Owing to insufficient rainfall the salts are not washed out of this soil so well as might be expected from its physical character.

Tables XVII, XVIII, and XIX give the mechanical composition and the results of the analysis of the separates of these soils.

Table XVIII would show these two soils to be somewhat similar to those of humid regions in respect to the distribution of the elements in the mechanical separates. Excepting the lime in the highly calcareous Indio fine sandy loam, the finer the separates, in general, the higher the percentage of the elements determined, and of course the less siliceous they are. Since these soils contain considerable alkali or water-soluble salts, constituents which would here appear in the clay, the content of the clay proper would be somewhat less than shown in the tables. In the case of the potash it would probably be considerably less. It will be observed that the sand of the Indio fine sandy loam contains slightly more potash than the silt. Were the apparent content of potash in the clay reduced by that which has been washed from the whole bulk of soil and concentrated in the clay, thus obtaining that of the clay itself, this true content would probably not greatly exceed that of the sand. Were the same correction made for the Fresno fine sandy loam, the clay would be about like the silt in potash content. The same considerations apply to the other elements, but doubtless to a less degree; but after making due allowance for this source of error, it would appear that the coarser particles are somewhat poorer in phosphorus, magnesium, and potassium.

TABLE XVII.—*Mechanical composition of the arid soils.*

Soil type and location.	2 to 0.05 mm. (sand).	0.05 to 0.005 mm. (silt).	0.005 to 0 mm. (clay).
	Per cent.	*Per cent.*	*Per cent.*
Fresno fine sandy loam, California	66.5	25.5	8
Indio fine sandy loam, California	46	29	24

TABLE XVIII.—*Partial chemical composition of the separates of the arid soils.*

Soil type and location.	P_2O_5.			CaO.			MgO.			K_2O.		
	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Fresno fine sandy loam, California	0.15	0.22	0.65	3.16	3.56	6.20	0.78	1.81	5.85	3.26	5.58	6.27
Indio fine sandy loam, California	.22	.27	.25	15.02	14.89	9.87	2.20	4.14	4.82	2.84	2.73	3.86

TABLE XIX.—*Content of the separates of arid soils calculated to percentages of the whole soil.*

Soil type and location.	P_2O_5.			CaO.			MgO.			K_2O.		
	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.	Sand.	Silt.	Clay.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Fresno fine sandy loam, California	0.10	0.06	0.05	2.10	0.91	0.50	0.52	0.46	0.47	0.17	1.42	0.50
Indio fine sandy loam, California	.10	.08	.06	6.94	4.35	2.36	1.02	1.21	1.15	1.30	.80	.92

COMPARISONS OF THE GROUPS OF SOILS.

It is interesting to compare the soils of one province with those of another. If the soils of the Coastal Plains be compared with those of the Piedmont Plateau and of the Appalachian Mountains, certain distinct differences are observed. The latter soils are residual—that is, they have been formed where now found or have been moved but short distances. The method of formation, in addition to pulverization, has been one of removal of certain parts of the rocks, either by solution or, mechanically, by moving water or air, leaving the present soil as a residue. The material forming the soil may differ but little chemically and mineralogically from the rocks whose breaking down has produced the soil, or it may depart much from them. An illustration of the latter is seen in the clays resulting from limestones.

The soils of the Piedmont used in this investigation contain abundant fragments of the original minerals undecomposed. The Coastal Plains soils have resulted to a large extent from material washed from the Piedmont Plateau and deposited in water at lower levels.

They have suffered from decomposition and solution more than have the Piedmont and Appalachian soils, and there has often been a greater separation of the finer from the coarser particles.

The tables show that the residual soils, Chester mica loam, Porters black loam, and Cecil clay, contain more plant-food constituents than do the Coastal Plains soils. This is especially true of the phosphorus, the potassium, and the magnesium. It is in the coarser materials, the sands, where the greatest difference in composition is found. In the sands of the residual soils the potash averages 1.60 per cent, in the sands of the Coastal Plains soils the potash averages 0.37 per cent, the sands of the residual soils being over four times as rich. In the clays the averages are, respectively, 2.86 per cent and 1.79 per cent, the clays of the residual soils being about one and a half times as rich as those of the Coastal Plains soils. A comparison of the potash content of the sand of a soil with that of the clay of the same soil shows that relatively as well as absolutely the sands of the residual soils are richer than those of the Coastal Plains. For example, in the Norfolk loam and the Crowley silt loam, having the least difference in the potash content of the sand and the clay of any of these Coastal Plains soils, the clay is three times as rich as the sand. In the Orangeburg fine sandy loam the content of potash in the clay is seven times that in the sand. In the Orangeburg sandy loam the ratio is 30 to 1. In the residual soils, on the other hand, the ratios are smaller, being 2.7 to 1 in Porters black loam, 1.8 to 1 in Chester mica loam, and 0.7 to 1 in Cecil clay. A similar comparison for the other elements will lead to the same conclusion—that the clays and the sands of the Coastal Plains soils differ more in composition than do those of residual soils.

The glacial soils consist largely of crushed rocks. Much of the material composing them has not been profoundly weathered. They are therefore quite similar in composition to the residual soils, and hence differ from those of the Coastal Plains. A comparison of the composition of the separates of glacial, residual, and Coastal Plains soils shows this. It is true of all constituents, unless it be phosphorus. If, as before, the potash content be taken for comparison, it is seen that the clays of the glacial and the residual soils contain about twice the percentage that the sands do, while the potash content of the clays of the Coastal Plains soils is five times that of the sands.

The sandy and the silty glacial soils are somewhat similar in percentage composition. Owing to the latter consisting to so large an extent of such fine particles, it might have been supposed that decomposition and leaching would have affected them more, and that there would have been a greater difference between the two classes than the figures show. The average potash content of the silty soils is slightly greater than that of the others, as may be determined from the table, being 2.16 per cent and 1.94 per cent, respectively. The magnesia is 0.74 per cent of the silty soils and 0.86 of the others; the lime, 1.08 per cent and 1.76 per cent; the phosphoric acid, 0.23 per cent and 0.22 per cent, the figures being in all cases averages calculated from the table. But the silty soils are loessial for the most part and were formed from material blown by winds from glaciated areas and deposited where now found, or of material that has since been reworked by water. Minerals rich in alkalies and alkaline earths, being relatively easily crushed, would form a larger percentage of these silty soils than they do of the original glacial soils; so that even if there has been a tendency to impoverish them by leaching, their originally greater richness enables the loessial soils to compare well with those strictly glacial.

We have but two soils of the arid region to compare with the twenty-five of humid regions. The latter were selected to represent soils of all classes—those of low, of medium, and of high productivity; sandy soils, clay soils, calcareous soils, and those intermediate between these several extremes. They may be taken as fairly well representing the humid soils. The two arid soils can not be considered to represent so well those of the region because of their limited number and similarity of texture, both being fine sandy loams.

If the separates of these arid soils be compared with those of soils that have been profoundly weathered and leached, such as the Coastal Plains soils and the shale soils, it will be found that the coarser separates of the former are richer relatively than the finer ones. If a like comparison be made of the arid soils with the glacial soils, the residual soils, and the calcareous soils, they are all found to be quite similar in so far as the distribution of nutrients among the separates is concerned.

It should be noted that our comparison of arid soils with those of humid regions is in no way similar to that made by Tolman (p. 10). He compared the solubility of the separates rather than their composition. It is well known that sands are often coated with colored iron compounds, so that what is called a yellow or a red sand becomes transparent, colorless quartz sand when treated with acid. Other minerals in the form of sand are also similarly coated. The finer portions, the silts and the clays, are often the most highly colored. It is generally impossible to tell whether the coloring compounds are simply finely pulverized and mixed with the silt and the clay, or whether the colors exist in the form of thin coatings on the grains of these materials. Schloesing[a] believes the latter to be largely the case. It seems reasonable to believe that the slightly soluble compounds existing in soils, such as the carbonates and the phosphates of the alkaline earths, the phosphates of iron and aluminum, the more soluble silicates and silico-aluminates, etc., may form coatings on minerals just as do the oxides and the hydroxides of iron. If the minerals or their decomposition products had been in solution and then separated out because of concentration of the solution by evaporation, the deposition would be on the grains. Even if the adhesive force were equal over surfaces of large and of small grains, so that the films would be of equal thickness, there would be a larger percentage in the coatings of small particles, since in these the surfaces exposed are much greater in proportion to mass. There would be a tendency for this coating film to thicken, for on the assumption of a surface attraction, it would be from the reserves of these slightly soluble substances and not from the films that more of the material would go into solution when water is added to the soil by rain or otherwise. The deposition would take place over the previous film as the soil becomes drier again. At length the action would be in equilibrium when the tendency to dissolve from the films and from the reserves is equal. While this is probably one of the reasons for the greater percentage of acid-soluble substances in the finer separates, it can hardly be doubted that because of their softness in comparison with such minerals as quartz the compounds containing the nutrients are more finely pulverized in soil making, and that they are therefore more largely reduced to the size of silt and clay. In arid regions this solution and deposition would not take place to so large an extent, since the soils are seldom thoroughly wet. Decomposition or alteration taking place on the surfaces of mineral grains, the latter would remain coated with decomposition products if there were lack of water to remove the coating or to continue the kaolinization process further. The coarser grains of soils are more likely to be thus coated in arid regions than in humid ones. The decomposition products being more soluble in acid than the original minerals, it may frequently happen that the sands of arid soils yield more material to the acid used in analysis than do the sands of humid soils, and for the reason given above. Tolman[b] believes this to be a general fact, and suggests the above explanation of it.

While the existence or nonexistence of these unremoved coatings of decomposition products would account for differences in the solubility of the mechanical separates of soils, they would cause no great difference in composition as shown by fusion methods, for the latter would show the total content of the grains; whether they be partially decomposed or not.

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[a] Compt. Rend., **135**, 601–605 (1902).

[b] Rept. Agr. Expt. Sta., Univ. Cal., 1898–1901, p. 40 et seq.

ROCKS, SOILS, AND SOIL SEPARATES.

Comparisons have often been made of residual soils with the rocks from which they were in large part formed. In many cases this can be done with considerable certainty that the proper materials are being compared. But most of the soils studied in this bulletin are far removed from the rocks whose disintegration produced them, and they are mixtures of such diverse materials that comparisons of the sediments with the parent rock can not be made. It may, however, be of interest to compare the separates of these soils with such well-known rocks as granites, syenites, gneisses, shales, and sandstones. Each of these classes of rocks varies considerably in ultimate composition, depending upon the proportion of their constituent minerals, but by taking several of each class some conception of common limits of variation may be formed. In the following tables the percentages of P_2O_5, CaO, MgO, and K_2O in a number of these rocks are given.[a]

TABLE XX.—*Partial composition of granites.*

Type of rock and location.	P_2O_5.	CaO.	MgO.	K_2O.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Granite, Currant Creek Canyon, Pikes Peak, Colorado	0.22	0.58	0.07	6.56
Biotite granite, Sentinel Point, Pikes Peak, Colorado	Trace.	.80	.04	4.92
Granite, Currant Creek Canyon, Pikes Peak, Colorado	.05	.23	.14	7.99
Biotite granite, Vermont	.11	1.13	.33	4.81
Soda granite, Minnesota	.20	.66	.58	4.97
Granite, Florissant, Colorado	Trace.	.15	Trace.	4.15
Granite, Montana	.06	1.26	.35	6.09
Aplite, Sierra County, California	.03	1.28	.05	5.18

TABLE XXI.—*Partial composition of trachyte-syenite rocks.*

Type of rock and location.	P_2O_5.	CaO.	MgO.	K_2O.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Nordmarkite, Vermont	0.13	1.49	0.40	5.97
Quartz syenite porphyry, Bearpaw Mountains, Montana	.10	1.32	.77	5.76
Biotite trachyte, Dike Mountains, Yellowstone National Park	.22	.93	.63	5.47
Soda syenite porphyry, Moccasin Creek, California	.11	.55	.24	.10
Soda syenite, Alaska	.06	2.66	.06	.39
Biotite trachyte, Dike Mountains, Yellowstone National Park	.25	2.78	.91	6.11
Augite syenite porphyry, Copper Creek Basin, Yellowstone National Park	.21	2.60	1.13	4.56
Augite syenite, Turnback Creek, California	.16	5.61	1.69	7.70
Syenite, Little Belt Mountains, Montana	.33	4.61	8.67	4.50
Syenite, Colorado	.35	3.77	1.24	5.05
Syenite, Crazy Mountains, Montana	.26	3.69	1.51	5.34

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[a] Clarke. Data of Geochemistry, 368–371, 463, 468, 534–535 (1908).

TABLE XXII.—*Partial composition of gneiss.*

Type of rock and location.	P_2O_5.	CaO.	MgO.	K_2O.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Sedimentary gneiss, Canada		0.35	1.81	2.50
Quartz-biotite-garnet gneiss, New Nork	0.11	2.40	2.40	1.98
Mica gneiss, Pennsylvania	.22	1.87	2.42	2.86
Gneiss, Maryland		9.69	5.98	1.56
Gneiss, sedimentary, Great Falls Potomac	.11	1.68	.95	1.35
Biotite gneiss, Michigan		1.87	1.26	2.85
Quartz-norite gneiss, Minnesota		5.99	3.62	.55

TABLE XXIII.—*Partial composition of sandstones.*

Type of rock and location.	P_2O_5.	CaO.	MgO.	K_2O.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Brown sandstone, Hummelstown, Pa		0.20	0.53	2.63
Ferruginous sandstone, Norfolk, England	0.42	2.43	.95	.48
From a "Sandstone dyke," Shasta County, Cal	.14	16.39	2.22	1.17
Miocene sandstone, Mount Diablo, Cal	.29	14.65	5.55	1.37
Composite of 253 sandstones	.08	5.52	1.17	1.32
Composite of 371 building sandstones	.06	1.05	.52	1.16
Sandstone from Hurley, Wis		.70	1.39	1.62

TABLE XXIV.—*Partial composition of shales.*

Type of rock and location.	P_2O_5.	CaO.	MgO.	K_2O.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Composite of 51 Paleozoic shales	0.15	1.41	2.32	3.60
Composite of 27 Mesozoic and Cenozoic shales	.20	5.96	2.67	2.07
Black Devonian shale, Morenci, Ariz	.08	3.40	4.16	6.74
Middle Cambrian shale, Coosa Valley, Alabama	.06	1.60	2.32	3.19
Bituminous shale, Dry Gap, Georgia	.31	.78	1.15	3.16
Shale near Rush Creek, Colorado	.17	12.09	2.12	2.31
Carboniferous shale, Elliott County, Ky	.08	9.91	1.91	.88
Cretaceous shale, Mount Diablo, California	.08	27.87	2.61	

A comparison of the figures in the above tables with those for the separates of the glacial soils in Table XII shows that the phosphates in these rocks and in the sands and silts are of about the same order of magnitude, and that they are appreciably higher in the clays. It would seem, then, that in so far as these soils resulted from rocks like the above there has been little change in the percentage of phosphates in the portions forming sand and silt, while there has been a concentration in the clays. The change of the minerals comprising these rocks to "clay" is a somewhat complex one. In so far as it is chemical it is mainly a loss of alkalis and alkaline earths by solution, and the taking up of water in kaolinization. The first process would tend to increase the proportion of phosphate, the latter to decrease it.

A similar comparison of the lime content shows that, while there is much variation in the percentage of this base, in general the granites are somewhat below and the syenites and gneisses somewhat above the several separates.

The sands and the silts of the glacial soils have much the same magnesia content as the granites and syenites, and the clays are richer. The gneisses contain more magnesia than any of these separates.

A comparison of the potash content shows that the granites and syenites are richer in this element than are any of the sediments—much richer than the sands and the silts. The gneiss rocks are about like the sands and poorer than the silts and clays.

These various relations may have come about by the mixing of the débris of very diverse rocks, those richer in the elements named with those poorer, or by the decomposition and leaching of the broken down richer rocks.

Of the soils formed from crystalline and metamorphic rocks by other than glacial action (pp. 19 to 21) the Chester mica loam and the Cecil clay, as a whole, contain about the same proportion of phosphate as do the granites and gneisses, the sands and silts being low, the clays relatively high. Calcium is a less abundant constituent of the soils than of the rocks. The soils contain about as large a proportion of magnesium as the granites and less than the gneisses. The syenites are variable in the content of this element, some of these rocks being poorer than the two soils and some richer.

Some of the separates of these soils are richer in the elements than the rocks and some poorer. Thus in general the rocks contain a greater percentage of phosphate than the sand and silt separates and less than the clays. All the separates are of lower lime content than the rocks. Their magnesia content is greater than that of the granites and less than that of the gneisses. The potash of the separates is very similar to that of the gneisses, but much less than that of the granites.

Porters black loam more nearly resembles the syenites in composition, and its separates are irregular when compared with the rocks. This soil is said to be derived from granites and gneisses in large part. The content of potash, lime, and magnesia in the whole soil is intermediate between that of the rocks as shown in these tables.

SUMMARY.

As a general rule the smaller particles of soils are richer in potassium, calcium, magnesium, and phosphorus than the coarser particles.

The concentration of these elements in the finer components is the more pronounced as the soils have undergone more extreme weathering.

In glacial soils and others resulting largely from mechanical processes the coarser particles are relatively high in the percentages of potash, lime, and magnesia.

The larger mechanical components contain these elements in forms which by protracted weathering will become more soluble, and they will ultimately be concentrated in the finer components.

Calcium is often rather low in clay soils resulting from the weathering of hard, compact limestones. It is generally abundant in soils recently formed from easily broken down limestones. The sands of these latter soils may contain a high percentage of calcium, probably as lime sand or as coatings on other large mineral grains.

A comparison of soils and soil separates with crystalline rocks indicates that in the process of the weathering of these rocks the phosphate remains of about the same proportion or slightly increases. The lime and potash seem to decrease in percentage, although minerals containing them are always present.

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Issued February 10, 1909.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS—BULLETIN No. 55.
MILTON WHITNEY, Chief.

SOILS OF THE UNITED STATES,

BASED UPON THE WORK OF THE BUREAU OF SOILS TO JANUARY 1, 1908.

BY

MILTON WHITNEY.

Part I. Results of Recent Soil Investigations.
Part II. Classification of the Soils of the United States.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1909.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., August 13, 1908.

Sir: The accompanying article, entitled "Soils of the United States," is composed of two parts. The first part consists of seven lectures covering the activities of the Bureau of Soils in the field and in the chemical and physical laboratories for the last nine years and discusses in a general way the most notable achievements during that period, coupled with suggestions for further research in the fundamental field of soil study. Each of these lectures being in a measure complete in itself, no effort has been made to give Part I the unity of development to be expected in a monograph, and certain duplications of statement occur which have been allowed to stand because necessary to the proper elucidation of the subjects considered under the main titles.

Part II consists of descriptions of the soil provinces, soil series, and soil types, the last particularly from the standpoint of crop adaptation. The extent and the distribution of the soils of the United States are also shown, and the whole gives the complete classification of soils up to January 1, 1908.

I have to recommend the publication of this work as Bulletin No. 55 of the Bureau of Soils.

Very respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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SOILS OF THE UNITED STATES.

PART I. RESULTS OF RECENT SOIL INVESTIGATIONS.

NATURE AND PROPERTIES OF THE SOIL.

Since the soil is a complicated system of four distinct classes of material, of which the constitution and properties are not thoroughly understood, and since these materials interact one upon another and at the same time are also acted upon by at least nine agencies, of the functioning of which agencies much is yet to be found out, the subject of soil investigation is one of the most intricate and difficult that has ever been undertaken. The subject of soil investigations as a laboratory study has been divided for convenience into soil chemistry, soil physics, and soil physiology, but the separation of these several fields is poorly defined and must be arbitrarily made, and can not be followed in a general paper of this character.

The soil in place in the field and in condition to grow plants consists of—

- Minerals.
- Water.
- Soil atmosphere.
- Nonliving organic matter.

These materials react on each other and in so doing affect the conditions for plant growth to such an extent that certain rather definite proportions must be maintained for successful crop production.

There are certain agencies common to soils which also react on or affect each other and the soil material. These are—

- Plants.
- Bacteria.
- Molds and fungi.
- Enzymes.
- Earthworms, etc.
- Radiant energy.
  - Light.
  - Heat.
  - Electricity.
  - Various other forms of radiant energy recently discovered.

SOIL MATERIALS.

MINERALS.

The grains of sand, silt, and clay contained in all soils consist of a large number of minerals, such as are also common to and make up the bulk of all common rocks, and, in addition, of very insoluble decomposition or alteration products. If a small sample of soil is thoroughly washed by decantation, being repeatedly pestled or violently shaken in a bottle with the water so as to loosen all the grains and wash out the fine material, or if it is merely acted upon by a dilute acid to remove the highly colored iron compounds, the variety of color and of form to be seen with the naked eye or with a hand lens will indicate the variety of mineral constituents. The common rock-forming and soil-forming minerals are—

Quartz.
Limonite—Turgite series.
Hematite.
Kaolin or kaolinite.
Feldspars.
Micas.
Apatite.
Hornblendes.
Pyroxenes.
Chlorites.
Tourmaline.
Rutile.
Calcite.
Dolomite.
Selenite.
Zeolites.

These minerals contain potash, phosphoric acid, lime, magnesia. and other mineral plant food. The way these plant food constituents go into solution and the way the concentration of the solution or the soil moisture is maintained at all times nearly constant and sufficient for plants is one of the most interesting subjects that has been investigated by the bureau. It is fundamentally important and has completely changed the point of view of soil investigators, leading to important lines of work which are clearing up the very intricate problems of soil fertility. The investigations referred to are on the solubility and absorptive power of the soil components.

SOLUBILITY OF SOIL MINERALS.

The common soil minerals given in the above list have been considered and are in fact very slightly soluble. They are of a similar order of solubility as ordinary glass, which in household use and even too often in our laboratories, until in recent years, we have considered practically insoluble. But it was found that in the finely divided condition in which these minerals exist in the soil, where an enormous surface is presented upon which the water acts, the solution quickly becomes saturated with the mineral plant food elements, and that the 25 parts of potash per million of solution and the 10 parts of phosphoric acid which would be dissolved in this water is ample for the needs of the plants, provided this concentration is maintained as the plants feed.[a]

The solubility of each mineral in the water and in connection with a mixture of so many different kinds of minerals as are found in soils makes the concentration and composition of the solution nearly the same for all soils. Finally, as the mineral plant food constituents are withdrawn by the growing plant the minerals readily give up to the solution sufficient to restore the saturated condition with respect to the various minerals. So long as there remains in the soil any of the solid mineral the amount that goes into solution and the influence of this on the solubility of other minerals would be quite independent of the quantity of the mineral in the soil, except for disturbing influences which will be discussed later.

An illustration or two may make this clear. If a teaspoonful of water is poured into a barrel of salt sufficient salt dissolves to make a saturated solution. If a cup full of water be then poured in, sufficient salt dissolves to saturate this also, and so while any solid salt remains the solution will be of constant concentration, regardless of the amount of salt or the amount of water. Salt is so very soluble in water, however, that one part of water will carry in solution over one-third of its weight of common salt, so that it would not take any very large quantity of water to entirely dissolve the barrel of salt, but in the combinations in which the minerals occur in the soil the soda and potash are so very insoluble that it requires about 1,000,000 parts of water to bring into solution 25 parts of potash.

Two calculations will show how this applies to the soil. With 1,000,000 pounds of water in contact with 5,000,000 pounds of soil the solution will contain 25 pounds of dissolved potash, although the actual amount of potash in the soil may vary from 30,000 pounds in one soil to 120,000 pounds in another.

Parts per million of potash and phosphoric acid in solution with a constant amount of water on a fixed quantity of soil of various compositions.

Constituents.	I.	II.	III.
Water	1,000,000	1,000,000	1,000,000
Potash, p. p. m.	25	25	25
Phosphoric acid, p. p. m.	10	10	10
Total soil	5,000,000	5,000,000	5,000,000
Potash reserve	30,000	60,000	120,000
Phosphoric-acid reserve	5,000	10,000	20,000

If in another case a soil of constant composition is moistened with successive quantities of water the concentration of the solution will be the same with each amount of water, although the actual amount of potash dissolved from the soil will vary with the amount of water.

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[a] The solubility and hydrolysis of soil minerals have been fully discussed in Bulletin 30 of this Bureau.

Parts per million of potash and phosphoric acid (a) in solution, and (b) based on dry weight of soil with varying amounts of water and a constant amount of soil of constant composition.

Constituent.	I.	II.	III.
(*a*) Solution:			
Water	1,000,000	500,000	250,000
Potash, p. p. m	25	25	25
Phosphoric acid, p. p. m	10	10	10
(*b*) Dry soil:			
Total soil	5,000,000	5,000,000	5,000,000
Total potash	30,000	30,000	30,000
Total phosphoric acid	5,000	5,000	5,000
Dissolved potash	25	12.5	6.25
Dissolved phosphoric acid	10	5	2.5

Finally, the composition of three soils is given, showing the amount of potash in reserve, the amount of potash in the solution, and all other mineral material going to make up a million parts of soil. The same thing is shown for the phosphoric acid.

Potash and phosphoric acid dissolved in the moisture of a soil containing 20 per cent of water.

Constituent.	I.	II.	III.
(*a*) Solution:			
Potash in solution	5	5	5
Potash in reserve	6,000	12,000	24,000
Other soil material	993,995	987,995	975,995
Total	1,000,000	1,000,000	1,000,000
(*b*) Dry soil:			
Phosphoric acid in solution	2	2	2
Phosphoric acid in reserve	1,000	2,000	4,000
Other soil material	998,998	997,998	995,998
Total	1,000,000	1,000,000	1,000,000

The initial rate of solution is so rapid that in a very short time after the water is mixed with the soil the solution is nearly saturated and will take up but very little more if it is left in contact for days or months.

If this potash is removed by plants, no sensible change in concentration takes place, as more immediately goes into solution. This can be illustrated in a very beautiful way with a special form of porous cell containing a small quantity of soil. By electrical endosmose, a slow stream of water drops continuously for months, carrying measurable quantities of potash; and phosphoric acid collects in the other compartment.

That the potash, phosphoric acid, and other plant food constituents resulting from the solubility of these minerals are available to plants, without any further change due to the weathering and decomposition of the minerals, as we formerly thought necessary, can be proved, as has been done repeatedly by growing plants to maturity in solutions so prepared.

ABSORPTION.

There is, however, another very important property of solids in contact with liquids which tends to control the concentration of the soil solution and to prevent undue waste of material, namely, the power the soil grains have of absorbing and holding on to dissolved salts. On the surface of a mineral particle moistened with water there is a pressure, which has been variously estimated at from 6,000 to 25,000 atmospheres, and which may be conservatively estimated as at least 10,000 atmospheres, or 150,000 pounds per square inch, acting at an inconceivably small distance from the solid surface. Ten thousand atmospheres or 150,000 pounds per square inch is approximately 15 times the muzzle pressure of a 12-inch gun (fig. 1). Under this surface pressure the concentration of the solution is enormously increased in the surface film, and chemical changes and reactions may take place which are impossible to bring about under laboratory conditions with solutions in beakers.

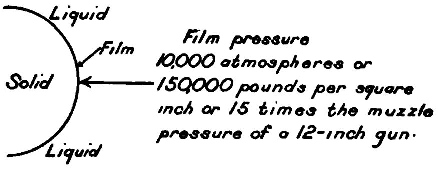
Liquid
Film
Solid
Liquid
Film pressure
10,000 atmospheres or
150,000 pounds per square
inch or 15 times the muzzle
pressure of a 12-inch gun.

FIG. 1.—Film pressure.

An example will at once illustrate the power and significance of this absorptive action. A solution of a very soluble potash salt was passed very slowly through some soil until the soil had absorbed 4,000 parts per million of its weight of potash, after which fresh water was passed through the soil, and the solution draining off was found to have the same concentration as before the soluble potash salt was introduced. The same thing occurred with a soluble phosphate. That this may not be a chemical change is indicated by the fact that certain organic dyestuffs dissolved in water will be similarly withheld by soils and will not be given up to fresh water, but will readily come out again by passing alcohol through the soil.

This absorptive power varies greatly with different soils and with different minerals, and varies for different substances or parts of substances: It is stronger for potash than it is for chlorine, and a weak solution of potassium chloride passed slowly through a soil comes through acid with hydrochloric acid, the soil having retained more of the potash than of the chlorine. If some silver nitrate is passed slowly through finely divided charcoal, the salt is decomposed by this selective absorption, some free nitric acid comes through, and small spangles of silver can be seen in the charcoal.

On account of this absorbing power it is altogether unlikely that fertilizers applied to soils in ordinary amounts will noticeably increase the concentration of the free water in the soil, as appears from the diagram (fig. 2), in which the curve representing absorption rises in practically a straight line until a high concentration is reached, when more and more of the salt goes into the free solution. The line *F* marks the possible increase of concentration represented by an ordinary application of fertilizer, which is seen to be far below the absorptive capacity of the soil.

As there must always be a certain distribution between the amount of mineral matter absorbed and the quantity in the free solution, and as this under ordinary conditions leaves about 25 parts per million of potash in the free solution, with an enormous reserve supply in the minerals themselves, it can readily be seen what an important factor this absorption is in regulating the concentration of the soil moisture. In attempting to study the relation of alkali soils to vegetation, an artificial mixture was made by adding 1 per cent of sodium carbonate to one of our eastern soils. No appreciable amounts of the salt could be found in an aqueous extract of it made subsequently, and plants grew well in the soil, whereas natural alkali soils showing 0.20 per cent of this salt are fatal to most plants.

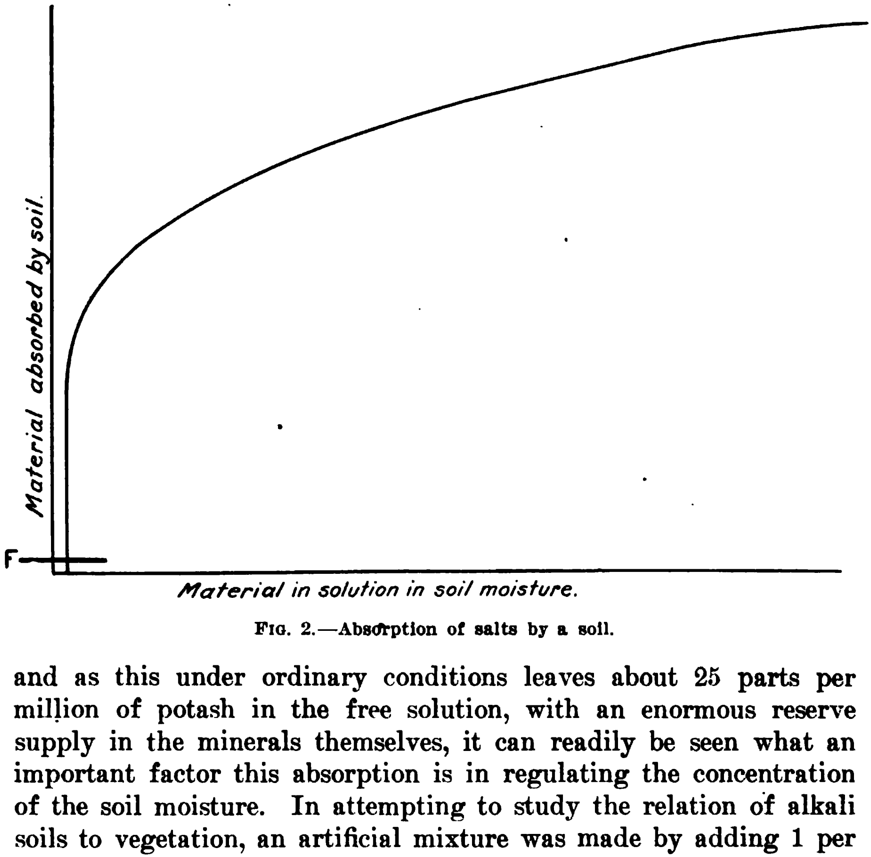

FIG. 2.—Absorption of salts by a soil.

It has been said that with the enormously high pressure on the surface film chemical changes may take place in soils which are not possible in the laboratory, and there is evidence to indicate that under ordinary conditions of temperature minerals which have not been formed in the laboratory actually form in the soil. The material for these minerals may come from great distances or from great depths, as a result of the slow but profound movement of ground waters. Too little consideration has been given to this subject of the range of movement of soil moisture. It is of the utmost importance in considering the permanency of soil fertility.

TEXTURE OF SOILS.

Having discussed the solubility of the minerals and their absorptive powers as a means of supplying the mineral plant food in the proper concentration for the use of crops, we will now consider the size of the mineral particles as determining the soil texture, which influences alike the relation to moisture and the chemical changes taking place through oxidation, especially of the organic bodies in the soil. The texture of the soil is expressed in the mechanical analysis by a separation into seven grades, the sizes of which are arbitrarily fixed. The results of the analysis show the percentages of sand, silt, and clay.

The texture determines to a large extent the relative power of soils to hold water. Under equal conditions of depth and exposure coarse-grained soils hold less moisture and more air than fine-grained soils, so that taken as a whole they contain less solution, and consequently a smaller quantity of nutrient material in solution. They also have generally a lower absorptive capacity and presumably permit a much more rapid and at times possibly an excessive oxidation.

When, aside from texture, the physical and chemical properties of the soil and its method of formation are alike, we have what we call a soil series, extending from the coarse gravelly or sandy soils on the one side to the finer silt and clay soils on the other, and in such a series the texture of the soil determines the distribution of crops.

It would be a comparatively simple matter to compare and classify soils according to the mechanical analysis or texture, but this standard alone is not sufficient, and the problem is in reality a very difficult thing, for in working out the relation of the soils to crops other factors enter which must be recognized in the correlation. One of the most important of these is the structure or the arrangement of the mineral matter. In some soils the mineral particles have a granular arrangement of flocculated masses, making the soil loose and porous. In others the grains appear to have no such coherency, but exist in a compact form, making the soil hard and compact. We also have the gumbo and adobe soils and others that are exceedingly plastic. Then, again, the amount and character of the organic matter influences not only the productive capacity of the soil, but its adaptation to crops, while the color of the soil has to be considered as indicative of certain obscure chemical or physical relations that influence the adaptation and productivity. The drainage features also come in, often with material influence on the organic constituents, on the aeration, and on oxidation processes. These factors all tend to make the correlation of the soils and the determination of their proper utilization and management a complicated matter. There are also differences shown in the relation of soil types to crops under different climatic conditions, the reasons for which, while fairly well understood from our recent investigations, would hardly find a place in a paper of this kind.

WATER.

As soon as water is introduced into the soil, whether by rain or by irrigation, it obeys certain physical laws which tend to bring about new equilibrium conditions. The soil moisture, with its dissolved mineral substances, forms the nutrient solution for the support of plants. We have seen how this material is obtained and how the concentration of the solution is maintained. We have now to see how this solution moves in the soil to supply the needs of the plant, which is fixed in its position and can not move around in search of water, as most animals can. Water may be contained in the soil in four different ways or conditions, in each condition exhibiting markedly different physical properties and peculiarities. These are combined water, or water of hydration, hygroscopic water, capillary water, and gravitational water.

CAPILLARY WATER.

The distinction between capillary and gravitational water in soils is by no means closely defined. Briggs[a] gives this definition:

> Gravitational water is that portion which is in excess of the amount which the soil is able to retain under existing conditions, and is consequently free to drain away. The capillary water is that part which would be retained in the capillary spaces under these conditions and which is capable of movement under capillary action. The hygroscopic water is that found on the surface of the grains, which is not capable of movement through the actions of gravity or capillary forces.

The capillary water is the principal source of supply of water to plants, and of the supply of mineral plant food constituents also, and is probably the seat of important biological changes in the soil. On the other hand, it undoubtedly plays an important part by carrying material from place to place in the soil and possibly in other ways.

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[a] Bulletin No. 10, Bureau of Soils, United States Department of Agriculture.

The relative amount of capillary water held by soils, other things being equal, is dependent upon the texture or size of the mineral particles and their arrangement, the depth of soil and facilities for drainage, and the amount, kind, and conditions of the organic matter. There is what we call the optimum or best amount, which varies with each soil. It ranges from about 20 per cent of the weight of dry clay soil and very much more for peat and muck soils to 4 per cent for some sandy soils. An important investigation, just completed, indicates that this optimum is a critical point for several of the important properties of soils.

At about 80 per cent of the optimum occurs the drought limit, at which point plants, unless especially protected by their structure as certain desert plants are, suffer through loss of turgidity and finally collapse, probably not because they are unable to obtain water from soils of that water content, but because the root removes water more rapidly from the surrounding soil than the water moves in the soil. Certainly seeds and probably plants have as great, if not greater, absorptive power for water than soils have. Air-dry seeds containing on an average about 14 per cent of water, if crowded into an equal weight of soil of optimum water content, after two days will leave the soil in an air-dry condition. A lima bean absorbs something over 100 per cent of its weight of water during germination. A single large lima bean introduced into a soil with the water content at or near the drought limit will completely air dry a thin layer of soil adjacent to its surface, yet fail to germinate for lack of sufficient moisture, although the soil as a whole contains as much as 15 per cent of its weight of water. This formed a very interesting investigation by the Bureau reported in Bulletin 23, in which it was shown that somewhat below the optimum the rate of movement becomes so slow as to be almost negligible. There are interesting lines of research still in all these fields.

OTHER FORMS OF WATER.

The water of hydration, which is chemically combined with the minerals, probably in the state of a solid in the mineral, is apparently of little direct use to plants in humid climates. We know, however, that under certain conditions dead and decaying organic matter does avail itself of the oxygen of the minerals, reducing the degree of oxidation, and there is reason to believe that it may also dehydrate certain minerals. Indeed, it has recently been suggested that certain desert plants may, under certain conditions, avail themselves of water gathered from such a source. Under certain conditions water so held may play an important, but, under ordinary conditions, a minor part in the soil economy through the chemical changes incident to the decay of organic matter. The question certainly deserves more study than it has had.

The hygroscopic moisture is that which adheres to an air-dried soil. Owing to the enormous force with which it is held by the soil grains and the high concentration of dissolved mineral salts due to this stress, it undoubtedly plays an important part in the chemical changes which take place. It has long been known that soils are particuarly productive after a long and excessive drought, and this is possibly due to the destruction of certain organic bodies in the high concentration of the surface film. Under ordinary atmospheric conditions loams and clay soils contain as much as from 4 to 8 per cent of their weight of hygroscopic moisture and soils rich in organic matter frequently much more than this.

The gravitational water marks an excess for most soils and is harmful rather than beneficial to most crops. However, in certain light sandy soils in low-lying position the beneficial effects of the retention of water, which in other positions would be harmful as gravitational water, is seen.

EVAPORATION.

At and above the optimum water content evaporation from soils is relatively very rapid. Below this point there is a marked change and the evaporation becomes very much slower and to a large extent takes place within the soil, instead of from the surface, the vapor coming out by the slow process of diffusion. A dry surface mulch, in which the capillary movement of water is exceedingly slow, conserves the moisture below by protecting from surface evaporation. Evaporation within the soil may take place at considerable depths and is a much more important factor than was formerly supposed.

SOIL ATMOSPHERE.

The soil atmosphere is considerably richer in carbonic acid gas and nitrogen than is the atmosphere above the soil. This results mainly from the consumption of oxygen in the oxidation of organic matter and the consequent liberation of carbon dioxide, which tends to diffuse out and to come into equilibrium with the free atmosphere. The diffusion process is slow, especially at considerable depths, and with many crops cultivation is necessary to secure more perfect aeration. So acute is the need of oxygen in some soils and under certain conditions of compactness and lack of drainage that the decaying roots and other forms of organic matter may deoxidize the soil minerals, as is apparent from the change of color of the soil.

NONLIVING ORGANIC MATTER.

Less is known about the nature of the organic constituents than about the mineral constituents of the soil. All kinds of animal and plant remains and their decomposition products are liable to occur in the soil. The great problems of chemistry of the soil will probably be found in a study of its organic constituents.

The color of a soil is not a sure indication of the amount of organic matter which it contains. Some characteristically black soils have less organic matter than some of the red or yellow soils. This appears to be a question of the condition of the organic matter, resulting from different processes of decay. In some soils it breaks down into a black product, the kind of material which we recognize by the undefined term "humus." In other soils the material is of a much more neutral tint or even colorless. Such soils usually yield, however, an intensely black solution when extracted with a dilute alkali, especially on standing in contact with the air.

A high degree of lasting fertility is usually associated with black soils, and they are usually considered more productive than yellow, red, or brown soils, but many notable exceptions to this rule are known. The trouble often experienced in obtaining satisfactory crops on newly reclaimed swamp land and fresh muck suggests itself as an example; also the high productive capacity of the brown or red soils of the Hagerstown series of central Pennsylvania and the Indian red soils of the Penn series in New Jersey. The density of black, as also the shade of color of the mineral matter of the soil, will often indicate to a trained observer differences in soils which mark decided differences in crop adaptation.. The reason for this forms one of the most interesting fields of investigation and one of great economic importance.

AGENCIES IN SOIL FORMATION.

PLANTS.

In view of the evidence presented by recent investigations of the Bureau it can no longer be doubted that plants produce waste products which, unless removed or altered in the soil, may become harmful or toxic to other plants of allied species. Organic bodies highly toxic to wheat have been separated from the soil in which wheat has recently been grown, though the soil did not contain these bodies before the wheat was planted. Wheat immediately replanted upon the soil which was shown to contain these products made only half the growth that a first crop made, while some of the organic matter introduced into an otherwise suitable nutritive solution likewise impaired the growth of wheat. The incompatibility of numerous plant associations, for example, weeds and crops, grass and trees, we now believe to be due to the excretion of one plant inhibiting the growth of another, unless the conditions in the soil are favorable to the rapid removal or change of the substances so formed. The mode of growth of roots and their corking over show us how a plant may protect itself from its own excreta and why a replanted specimen of the same species grown on what must now be considered a contaminated soil can not protect itself from the excretion of the plant which has recently occupied the spot. In the fact that some varieties of plants appear to be not at all affected by the excreta of other plants, and may even help to destroy such excreta, we have the reason for the beneficial effects of rotation of crops.

BACTERIA.

The great scavengers of the soil are those bacteria whose office seems to be to work over and change the organic remains of plants and animals. Under certain soil conditions forms of bacteria thrive, which, through their products, change and purify the soil while the crop is growing and after the crop is harvested. Under other conditions, however, other forms of bacteria flourish, and bring about the production of substances very toxic to plants. Such conditions probably prevail in the subsoil, and this explains the injurious effects often seen in turning up too much of the subsoil in plowing. Association of certain forms of higher plants and associations of bacteria are killed by accumulations of their own excreta, and bacteria are influenced by the excreta of other forms, as the higher plants are.

MOLDS AND FUNGI.

The action of molds and fungi in the soil may frequently be beneficial to plants, but it has been shown that their products or excreta are often very detrimental and toxic. This seems to be the explanation of "fairy rings," and recent investigations appear to show other cases of toxic products in the soil arising from the action of molds on the living or dead organic matter of the soil. Associations of molds and bacteria are generally incompatible. The humus extracted from soils appears to be sterile to bacteria, but is readily attacked by molds under conditions suitable for their growth.

ENZYMES.

Enzymes are undoubtedly essential in the fermentation of organic matters and the production of new organic compounds. They play a very important part in the fermentation of manure and the preparation of it for its best effects on certain soils. They also play an important part in the decay of green manures in the soil. Finally, the characteristic reactions for enzymes may be obtained from many soils. Enzymes are active oxidizing or reducing agents, but what part they play in the sanitation of the soil besides the functions indicated is not clearly understood, as the subject has not been specifically studied.

RADIANT ENERGY.

Very little recent progress has been made in the study of the various forms of radiant energy upon the soil or upon the problems of soil fertility. Heat, it is known, has an important effect upon soil changes, but how and to what extent it influences the soil and with what results is not clearly understood. It has been suspected that various forms of electrical energy may be effective also in the economy of the soil, and recently it has been suggested that the various recently discovered forms of radiant energy may have some part to play, but how or to what extent is not even conceived at this time.

FERTILIZERS AND MANURES.

Organic manures are active oxidizing or reducing agents according as they give oxygen to or take it from other bodies, in either case tending to break down into the simplest compounds and so to aid in the destruction or change of the organic matters in the soil. In this way they operate to improve the sanitary conditions of the soil. While it appears reasonable to expect that the mineral matter contained in the manure may benefit some soils, experiments in which the organic matter and mineral matter of the manure were separated indicate that the main beneficial effect is derived from the organic portion. Nitrogenous organic material has a beneficial effect on soils only when decomposition proceeds in a certain way under certain favorable conditions. Other plants having as high a mineral content do not in their decay have so marked a beneficial effect on the soil. The effects of manure and green manure on the soil may be deleterious to plants during the initial stages of decay, but become beneficial after a few days' fermentation or decomposition in the soil under proper conditions.

Commercial fertilizers, as we have seen, do not increase permanently the concentration of the free moisture in the soil, but are absorbed into the film of high concentration attached to the soil grains, the seat of the most profound chemical activity. It appears that fertilizers act upon the soil rather than on the plant, but in conjunction with the plant they can often accomplish more good in improving the sanitary conditions of the soil than either the fertilizers or the plant alone, and that fertilizers do act upon and render less harmful some of the toxic organic bodies liable to be encountered in the soil. Support is lent to this view by the importance of the form of compound and the proportion of the fertilizer ingredients. All of the potash salts are not equally effective on all soils or with all plants. Some of the potash salts, as, for instance, the iodide of potash, are harmful to plants, while the chloride is generally less safe than the sulphate. The nitrate and sulphate of ammonium and the different forms of organic nitrogen used have different effects, even when used on the same soil for the same crop. The conclusion is that it is the compound or material as a whole that determines in large measure the effects which will be produced, rather than simply the amount of potash, nitrogen, or phosphoric acid which the substance contains.

These matters can now all be easily and exactly studied by methods of research recently devised, and there is no line of study more interesting or practical than those presented or any that will throw more light upon the practical methods of soil management.

THE CLASSIFICATION OF SOILS.

MATERIAL.

The basal material of the soil, as we have seen, is an aggregation of mineral particles of various sizes, ranging in the fine earth from 2 mm. in diameter to a size so small as to be hardly distinguished with the most powerful microscope. The difference of size of the particles and the different proportions of the different sizes give rise to the texture and influence the various physical properties, such as the water-holding power, the aeration, etc.

The slight solubility of the minerals and their high absorptive capacity provide in the soil moisture a dilute nutritive solution of nearly constant concentration, but of sufficient strength for the needs of plants, as far as their requirements for the mineral plant-food elements is concerned. An important point, and one which has been given too little consideration in the study of soils in the past, is the very wide distribution through them of all the common minerals and the tendency under such conditions as prevail for all chemical changes to produce the most insoluble products consistent with the nature of the material. There has been a failure to appreciate that under equilibrium conditions there is always a definite distribution between the substance dissolved and the solid substances in contact with the solution.

There are associated with the minerals of the soil various organic bodies resulting from the decay of former vegetation or excreted by growing plants which affect more or less the sanitary conditions of the soil and its healthfulness for crops. Important chemical changes must occur in disposing of this waste product to preserve the proper conditions in the soil, and in some soils such sanitary conditions are more easily maintained than in others, whether we refer to natural changes within the soils or to artificial treatment. Such chemical properties and powers appear to be associated in some way not at all well understood with the mode of formation or deposition of the soils as well as with the character of the material from which the soils have been derived.

ROCKS AND SOILS.

Soils are undoubtedly formed from the disintegration and decomposition of rocks, but rocks may also be formed from the consolidation of soils. These may again break apart into soils and be again reconsolidated into rocks. The most important fact in this connection is that all of our common rocks contain practically all of our common rock-forming minerals, though in widely varying proportions. One has but to look at a specimen of a common sandstone or shale to see the plates of mica and other forms of minerals associated with the quartz. We find the same minerals in the sandstones, limestones, and shales as in the granites, gneisses, and schists. The differences, aside from variations in the relative proportions, appear to be that one set is formed by water deposition with or without pressure under ordinary temperatures, while the other set is formed under conditions of high degrees of pressure and temperature. There are of course exceptions in the case of any pure sandstone as there are in the case of exceptionally pure forms of igneous rocks. There is a question among geologists whether what we consider the oldest crystalline rocks in the United States have not in fact been formed by consolidation under great pressure and high temperature from assorted material worked over from still older and more primitive rocks.

It is a mistake to suppose also, as we often do, that sandstones always give rise to sandy soils. Some of our most tenacious clay soils come from sandstone, as, for instance, the Penn clay from the Triassic red sandstone rock.

PHYSICAL PROPERTIES OF THE SOILS.

The most obvious of the physical properties of a soil are its texture and color, both of which indicate important soil differences influencing crops.

TEXTURE.

The texture of a soil is determined by the proportion of the different-sized mineral particles it contains. This proportion is determined by the method of mechanical analysis, in which the soil is first shaken for a long time in water to separate thoroughly the mineral particles and then the fine material washed out, this being still further divided, utilizing for the purpose the known law that different-sized particles subside at different rates. The coarser particles are separated by means of sieves with different-sized openings, and thus the soil is finally divided into seven grades, the limits of which are arbitrarily fixed.[a] From the relative proportions of these the texture of the sample is determined.

In naming a soil the texture of the surface soil and of the subsoil to a total depth of 3 feet in the humid States and of 6 feet in the arid States is taken into consideration. We have soils, therefore, with a sandy surface soil and a clay subsoil; less frequently a clay soil and a sandy subsoil. We have soils with a loam top soil and a clay subsoil, or a loam top soil and a loam subsoil. Furthermore, in the descriptions of a soil in each area surveyed the texture and character of both the top soil and the subsoil are given, so that when a soil is specifically referred to by name, as for example, the Norfolk sandy loam, the term " soil " in this sense refers to the entire profile, including the top soil and the subsoil.

In correlating soils, therefore, and deciding that the soil of one place is similar to and is to be given the same name as the soil of another place, we must take into account first of all the texture of the entire depth of 3 or 6 feet, as the case may be. In sampling soils we always keep separate, for the purpose of mechanical analysis, the top soil and the subsoil, and if the subsoil shows two phases or layers of different texture we separate these also. The experienced soil-survey man can judge very accurately of the texture of the soil material, but even his judgment, before being accepted, is always confirmed by mechanical analysis.

Where soils have a common origin and differ only in texture and are alike in color and in physical properties other than those effected by texture, they are arranged in what we call a series, having the soil generic name with qualifying textural terms. We have, for example, the Miami gravelly loam, the Miami fine sand, the Miami sandy loam, the Miami silt loam, and the Miami clay loam as prominent types in the Miami series. In this particular series we have fourteen types, and possibly two or three other types will be encountered. In the Norfolk series we have twelve types.

Other things being equal, as the texture varies the water-holding capacity of the soil will also vary, the light sandy members of the series or the sandy types holding on the average not over 4 per cent of water, while the clay members at the other end of the series will hold 20 per cent of moisture. With this difference in moisture there is a corresponding difference in the soil atmosphere and oxidation is usually much more rapid in the sandy members than in the clay members of a series.

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[a] Bulletin No. 24, Bureau of Soils, U. S. Dept. of Agr.

The effect of differences of soil texture upon the adaptation of soils to crops and upon crop production is well known. For some reason which we can not yet definitely explain, under humid conditions wheat is not well adapted nor will it produce bountiful crops on the sandy members of a series. Early spring crops, such as lettuce, peas, and early potatoes, produce good yields and ripen much earlier in these sandy soils, and as a rule they are adapted to these truck crops. In the Atlantic Coast States corn comes next in being best adapted to the loam members of a series, then wheat on the heavier loam and clay-loam members, and lastly, grass on the heavier clay loams and clays. This is a general statement, to which there are many exceptions on account of modifying conditions which will be presently discussed.

In the low-lying portions of the Coastal Plains, where drainage is somewhat deficient and the capillary water content of the Norfolk sand is supplemented by a suitable amount of gravitational water, very good crops of wheat are produced if the intensive methods used in the production of truck crops be followed. In the Middle West, under the climatic conditions which prevail, corn is grown on the black clay loams and clays, while in the far West, under the climatic conditions and prevailing methods of that region, the influence of the texture of the soil is not so apparent.

Where the structure of soils differs for some natural reason, as, for example, where they run together and form a compact hard mass in a dry season, or, to take another case, maintain a loose and open structure, we know that this does influence in some way the drainage conditions, the conditions of aeration, the ease of root penetration, and in general those processes which go on in the soil and make for those sanitary and physical conditions proper for crop production. Where such differences in structure are observed, even if the texture and color of the material is the same, the soils are not put into the same series, but are placed perhaps in another series having similar structural peculiarities or for the present are thrown into a miscellaneous and unclassified group.

If the texture and structure of two soils is the same and one differs in a marked degree from the series color, and that departure is fairly constant and typical of the area covered by the soil, this soil likewise is thrown out of the series, because we have reason to know, by observation of the growing crops, that this color difference stands for a difference in the chemical changes which go on in the soil and which are necessary for the welfare of certain crops.

In the classification of soils, therefore, the texture is used to determine the place in the series; the structure and color to determine what series the soil can be correlated with.

COLOR AS INDICATIVE OF FERTILITY.

Too little attention has been given to what appears to be the influence of color, or some associated properties of the soil which determine the color, on the yield and qualities of the crop. In mapping the soils in the field there is something in the physical aspect which indicates to the soil expert that some difference will be found in the character of the crops produced or in the methods of cultivation or fertilizers required to produce satisfactory yields. The soils are mapped in the field, usually from obvious physical differences, the laboratory work being mainly to confirm the man's judgment as to texture and to investigate properties which may explain observed differences. It is not wholly a matter of the relation of the soil to water which influences him in judging of the structure, for the field classification of soils goes on in all seasons and the soils are seen in all conditions of moisture, from excessively wet to excessively dry, yet the expert can at all times tell, by an examination of the soil material, the differences in the structure and the relation to drainage, and can judge, moreover, of what can be accomplished in changing the conditions by artificial means.

Careful observation has shown that the black, red, yellow, blue, and white soils of the Coastal Plains are essentially different in their properties and in their relation to the yield and quality of crops. The soil man knows that on the red soils of the Orangeburg series, whether the Orangeburg sandy loam, the Orangeburg loam, or the Orangeburg clay, he will get a tobacco from Cuban seed which has a certain texture and a certain aromatic quality which can not be obtained from the same seed planted on the yellow soils of the Norfolk series, in adjoining fields, and under identical climate conditions. The texture of the soil in this case will influence the texture of the leaf. On the light soils of the Orangeburg series he will know that the product will be a thinner leaf and that on the heavier soils of the same series the leaf will be heavier and contain more gum, but will have the same aromatic qualities. On the yellow soils of the Norfolk series in our South Atlantic and Gulf States he will get the finest quality of wrapper leaf of the Sumatra type, without aroma, with little gum, but with an elastic texture and a bright glossy finish which can not be equaled on the red Orangeburg soils. Why the color of the soil should indicate this is not apparent. It does not seem probable that it is due to the actual difference in color or even to the differences in oxidation and hydration of the minerals which occasion the color, but to some property in the soil which determines that under similar climatic conditions the color of the one soil derived from the same material of the Piedmont Plateau, laid down so far as we know under similar conditions, shall consistently be red, while the soil of an adjoining field may be yellow. The chemical properties exhibited in the differences in color of these two soils, so far as we can now see, have an effect upon the chemical changes influential on the quality of the crop.

That color is to a considerable degree indicative of productiveness is shown also by the change which takes place in the subsoil between the time when it is freshly turned up and when brought into a condition favorable for crops. In the Atlantic Coast States, particularly, it is not uncommon to find subsoils deleterious to crops if too much of the material is turned up at any one time by the plow, and it is interesting to watch a skillful gardener improve a piece of raw land of such character. He adds a little manure and spades it in lightly, and still the soil is not in first-class condition for a crop. He lets this lie four or five weeks and respades and finds the color gradually and slowly changing. It may take three or four years to produce a fertile soil out of the raw piece of land or out of a subsoil in this way, and his experienced eye can tell from the color changes the rate of progress with which the change is taking place. The gardener knows that by his methods of soil fermentation and by the increased oxidation brought about by intelligent methods of handling certain changes have taken place in what was formerly the raw subsoil to fit the material for crop production. In this case it is not the lack of organic matter, for this can be supplied at once, but it is the form or the condition of the organic matter in the subsoil which indicates to him unfavorable conditions for plant growth, and these conditions he ameliorates or changes both by the addition of organic manures and by judicious cultivation.

The soil expert knows what can be accomplished by these artificial means, but he knows that no means are available to produce the Cuban tobacco of high aroma on the yellow soils of the Norfolk series or the Sumatra type of wrapper leaf of equally high quality on the red soils of the Orangeburg series. He also knows from experience that with the highest art of cultivation the black soils of the Portsmouth series will produce different crops—or the same crops of different quality—than will the black soils of the Houston series.

The red color of the soils of the Cecil series and the yellow color of the Chester soils are recognized by our field men to indicate differences in their relation to crop production and to cultural methods, and there is no question in their minds that the soils should be separated into different series.

In the glacial regions the black soils of the Marshall series and the yellow soils of the Miami series are another striking example of differences in crop adaptation indicated by color differences. The greater productiveness of the darker soils is not dependent upon the amount of organic matter, because two soils may have the same amount of organic matter and yet have entirely different crop values, but is due, as we think, to differences in the condition of the organic matter. This is probably determined by certain chemical changes, which may be the result of biological agencies, and which in any event are apparent in the color differences of the soil.

Instances of this kind could be multiplied, but it seems unnecessary. It is on account of these slight differences in structure and slight differences in color that we still have a number of soils among the types so far mapped in the United States that we have not been able to correlate into series. In the Coastal Plains there are five loams and five silt soils, for example, having approximately the same texture as other soils which have been placed in series, but differing so much in structure or in the shade of the color that they have never been classified. We can at present find no relationship between them and other soils, and this is borne out by the experience of farmers, who testify as to differences in soil management, crop adaptation, yield, or the quality of the product, which justifies us in excluding them from any of the established series.

Too much emphasis can not be laid upon the fact that we do not consider the color itself a factor in crop production, but only as indicative of soil conditions, of chemical powers or of the kind of decomposition which normally takes place under cultivation, affecting in one way or another either the yield or the quality of the crop produced.

SOIL PROVINCES OF THE UNITED STATES.

We thus have soil series comprising types alike in all respects except in texture and in such physical properties as texture determines. We then have the types in these series and a number of unclassified types, which are put for the time into a group of miscellaneous soils. The complete scheme of classification, so far as perfected by the Bureau of Soils, also provides for the grouping of these series and the associated miscellaneous types into thirteen great soil provinces, as shown in the map accompanying this bulletin. This broader grouping depends upon certain similarities in the soil, due in part to the character of the original material and, in part, to dominant agencies operating in the formation of the soils.

FACTORS GIVING RISE TO SOIL PROVINCES.

The principal factors which have been contributory to our soil provinces will be discussed under the following heads, the actual description of the provinces, their series and soil types being reserved for the second part of this bulletin. The main idea intended to be conveyed in this brief summary is the fact that the soil minerals found in the different soil provinces do not materially differ in character, but that the soil peculiarities characteristic of the different provinces are the results of the operation of the different agencies about to be discussed, as follows:

- Climate.
  - Humid.
  - Arid and semiarid.
- Heat metamorphism.
- Ice, rushing glacial water, and wind attrition.
- Lakes.
- Oceans.
  - Wave action.
  - Simple repeated submergence.
  - Same modified by shell fish débris.
- Rivers.
- Topography.
- Volcanoes.

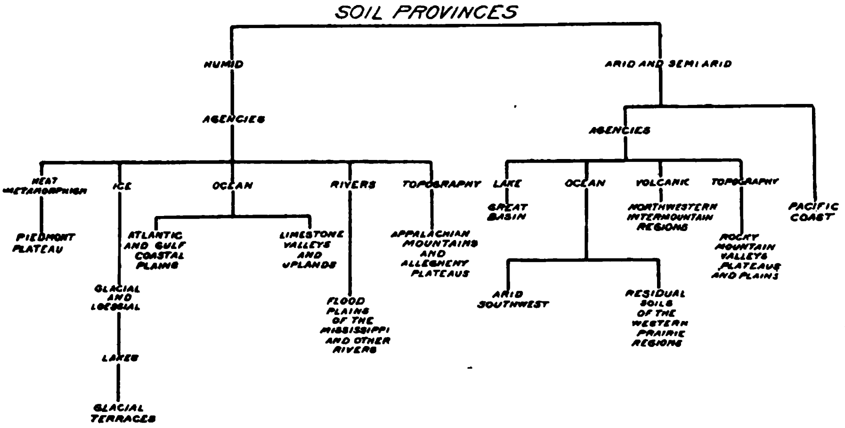

SOIL PROVINCES
HUMID
AGENCIES
HEAT METAMORPHISM
PIEDMONT PLATEAU
ICE
GLACIAL AND LOESSIAL
LAKES
GLACIAL TERRACES
OCEAN
ATLANTIC AND GULF COASTAL PLAINS
LIMESTONE VALLEYS AND UPLANDS
RIVERS
FLOOD PLAINS OF THE MISSISSIPPI AND OTHER RIVERS
TOPOGRAPHY
APPALACHIAN MOUNTAINS AND ALLEGHENY PLATEAUS
ARID AND SEMI ARID
AGENCIES
LAKE
GREAT BASIN
OCEAN
ARID SOUTHWEST
RESIDUAL SOILS OF THE WESTERN PRAIRIE REGIONS
VOLCANIC
NORTHWESTERN INTERMOUNTAIN REGIONS
TOPOGRAPHY
ROCKY MOUNTAIN VALLEYS PLATEAUS AND PLAINS
PACIFIC COAST

FIG. 3.—Soil provinces of the United States and the dominating factor in their formation.

CLIMATE.

Each of the agencies stated has had or has a profound effect upon the constitution or properties of the soil material, and each influences directly or indirectly crop adaptation and soil management. The arid and humid conditions marking broadly the western and eastern half of the United States have given rise to marked differences in soil features. Under western arid conditions there is little noticeable difference between the soil and subsoil in texture and but little difference in color. There is remarkably little true clay soil, such as encountered in the East, sands, loams, and silts predominating. Many soils of differing textures have adobe properties, which are unusual in the East. The soils and subsoils as a rule have neutral colors, generally gray or black, although many of the rocks give brilliantly colored disintegration products. The soils frequently contain quite noticeable amounts of soluble salts, which accumulate in places, resulting in alkali conditions. The soils generally contain less organic matter than the soils of the East, and a large proportion of this is in the stable form. The soils generally, and notably the subsoils, appear freer of toxic organic bodies than eastern soils and are almost universally capable of producing larger yields under irrigation. When irrigated, or even when dry-farmed, the texture is not so controlling a factor in the distribution of crops as in the soils of the East. Plants develop a much deeper root system than on soils of the East. With little difference in texture between soil and subsoil, with the infrequent rains, and the dry atmosphere and generally rapid surface evaporation, a more efficient surface dry mulch can be maintained, making it possible to produce good yields of crops with remarkably light rainfall, frequently without any at all during the growth of the crop.

HEAT METAMORPHISM.

This agency has given us the materials from which the soils of the Piedmont Plateau, which have generally a bright red or yellow subsoil, the former characteristic of the Cecil and the latter of the Chester soils. The material found in the Piedmont soils has contributed directly or with intermediate changes to most of the soils of the United States, but through the agencies of soil deposition, about to be discussed, the soils outside this province have altogether different properties. It must be remembered that our sandstone and shale are débris from these crystalline rocks worked over and sorted out by water and reconsolidated into rock, and that our limestone soils are the same materials contained as impurities in the limestone rock, and that all these common rocks contain most of the common minerals.

ICE, RUSHING GLACIAL WATERS, AND WIND ATTRITION.

These agencies, which in common grind up the crystalline rocks, sandstones, shales, and limestone, give rise to soils very different from the soils of the Piedmont Plateau, where the crystalline rocks have disintegrated in place, different from the soils of the limestone valleys, and different from the soils derived through degradation of sandstone and shale in place. The granitic material so ground up does not take on the bright-red color of the Cecil or the shade of yellow of the Chester soils. The ground-up limestone does not take on the brownish-red color of the soils of the limestone valleys. There are two main series of glacial soils—the yellow Miami soils of the rolling uplands and the black Marshal soils of the prairies. When limestone fragments evidence the incorporation of limestone material, and often when these larger fragments are absent, the fine earth contains sufficient lime carbonate to cause an effervescence with acid, which is not the case with the soil of the limestone valleys, which are characteristically low in lime content. Furthermore, the physical properties of these glacial soils, when the rock origin can be determined, is entirely different from the soils resulting from the disintegration of similar rocks in place without the glacial area. These physical differences and their connection with the causes that bring about the difference in color has not been determined, nor can it at present be determined or expressed in any specific way. It can, however, be detected by a trained observer, and even by the casual observer, that there is a difference, and this difference, whatever it may be, gives a different character to the soils, requires different methods of soil management, of fertilization, and of cropping. The difference in the material has impressed itself upon the topography, and erosion has given the region a character peculiar to itself.

LAKES.

Around the Great Lakes, and elsewhere throughout the glacial region, where this glacial material was reworked when lakes covered larger areas than at present, the material presents itself in still a different form, due to the intervention of water action. The lake terraces and old lake flats were formed, giving rise to soils adapted to special crops that find here peculiarly favorable soil conditions.

OCEANS.

More striking perhaps, because the soils are more direct in derivation and adjacent in position, is the comparison between the Piedmont Plateau soils and those of the Atlantic Coastal Plains. The soils of both provinces have been formed from the same material, but in the case of the Coastal Plain types the material has been washed down, submerged beneath the ocean, elevated, again submerged, and reelevated a number of times.

The material here has again changed its character. The same minerals are found in the soils, but the color, texture, and physical properties of the soil material is changed. The material, it is true, has been sorted out by running water and by wave action, but the clays of the Coastal Plain are different from the clays of the Piedmont Plateau; so are the loams; so are the silts and sands. The Orangeburg soils, it is true, are red, but it is a different color from the red of the Cecil soils. The Norfolk soils of the Coastal Plain have a yellow subsoil, but it is different from the yellow of the Chester soils of the Piedmont. The variegated colors of the Susquehanna, changing from brilliant red to yellow, blue, or black, have no prototype in the

Piedmont Plateau, although derived from the same material. While differing among themselves there are certain similar characteristics running through the soils of the Coastal Plain which result from their common origin and mode of formation, and which mark them as belonging to a different soil province than the soils of the Piedmont Plateau. In this region also peculiarities in the physical properties of the soil and consequently in the character of erosion result in a different form of land surface.

The Gulf Coastal Plain, derived and formed in the same way though locally modified by glacial material, has soils in common with the Atlantic Coastal Plain, although many new soils are encountered here, owing to the conditions of sedimentation, and it is possible that this region should be set off as a separate province. Where during the periods of submergence shellfish have abounded, we may have calcareous deposits in the form of marl, coral rock, and true limestone.

RIVERS.

Along the course of the large rivers we have a class of soils differing again in color and in physical properties from the material from which they were derived. The color and physical properties are changed with any extended river action, and yet all soils so formed have certain characteristic properties and peculiarities which group them in a separate soil province. Even within the Piedmont Plateau itself the soils derived from the upland, worked over, and deposited by river agencies are so changed as to constitute new types.

TOPOGRAPHY.

The influence of abrupt topographic changes, as in our mountain ranges and elevated plateaus, tends not so much to modify the character of the soil as does the action of the other agencies mentioned, but rather by reason of the slope and elevation it has the effect of adapting them to special crops and to make necessary different methods of soil management. The Porters clay of the Appalachian region would be the Cecil clay if on the Piedmont Plateau, but from its position, slope, and elevation it is essentially a different soil to the farmer, and is put in a different province because of this relationship with other soils of the Allegheny Plateau.

VOLCANOES.

There are also in the Northwestern States a considerable area of soils derived directly from true volcanic material, such as basalt, volcanic ash, and other forms of volcanic material.

UTILIZATION OF SOILS.

THE PROBLEM.

The art of soil management is so to manipulate and handle 4,000,000 pounds of raw material—the weight of soil 1 foot deep on an acre—at an average cost of $10 or $12 as to produce the greatest quantity of food and clothing and still leave the soil unimpaired for future generations. The highest art is usually ascribed to the individual who secures the greatest net returns in money or the best grade of product. The best chance of attaining the highest art is in the long run in the hands of the man who has a thorough understanding of the nature of the soil and how to handle it, of the crops adapted to it and their needs, and of the market demands; in other words, who can make the most of the proper utilization of the conditions and resources above mentioned.

THE CLIMATIC CONDITIONS.

The first condition determining the proper agricultural use to which any soil can be put is climate, which limits broadly the zone or area in which certain field crops can be grown, and which affects the yield and quality of the products to a very marked degree, even within the area of profitable cultivation. The climate of the continental United States varies greatly, probably much more than is generally realized. In the southwest we have the semitropical arid climate. In southern Florida we have the semitropical humid climate. Over the country as a whole we have from more than 60 to less than 10 inches of rainfall and a range in mean temperature of more than 70° F. to less than 40° F. The elevation of our arable lands varies from below sea level to over 6,000 feet above. We also have varying types of rainfall; the greatest precipitation may occur in the winter months or may come in the summer months. We have great differences in relative humidity and in sunshine. We have differences in the range of temperature, both seasonal and daily, and we have differences in the length of the growing season. Finally, we have differences due to slope, exposure, large bodies of water, and to other conditions too subtle for us to measure, which may determine the special fitness of a soil for a particular grade or quality of product. So complex are all these conditions and so indeterminate their individual or combined influence on the crop that no exact expression can be given for the climatology of any particular locality. In fact, with all our recent advance in meteorology, it is generally conceded that we still know very little about climatology as this term is used here.

The very simplest conditions, however, namely, the distribution of the mean annual precipitation and the mean annual temperature, will indicate the great variety of meteorological conditions which prevail in the continental United States.

The following table and diagram (fig. 4), made up from Weather Bureau maps and records, show the normal annual precipitation in the United States and the proportion of the area covered by each of ten grades of precipitation.

Normal annual precipitation in continental United States, showing percentage of area having normals within certain limits.

Area.	Rainfall.	Area.	Rainfall.
	Inches.		*Inches.*
9 per cent	0–10	16 per cent	40–50
30 per cent	10–20	10 per cent	50–60
13 per cent	20–30	1 per cent	Over 60
21 per cent	30–40		

From this table it will be seen that about 30 per cent of the area has a precipitation of 10–20 inches and 21 per cent has a precipitation of 30–40 inches.

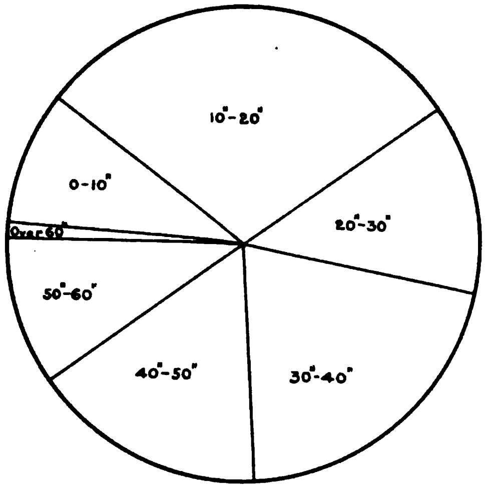


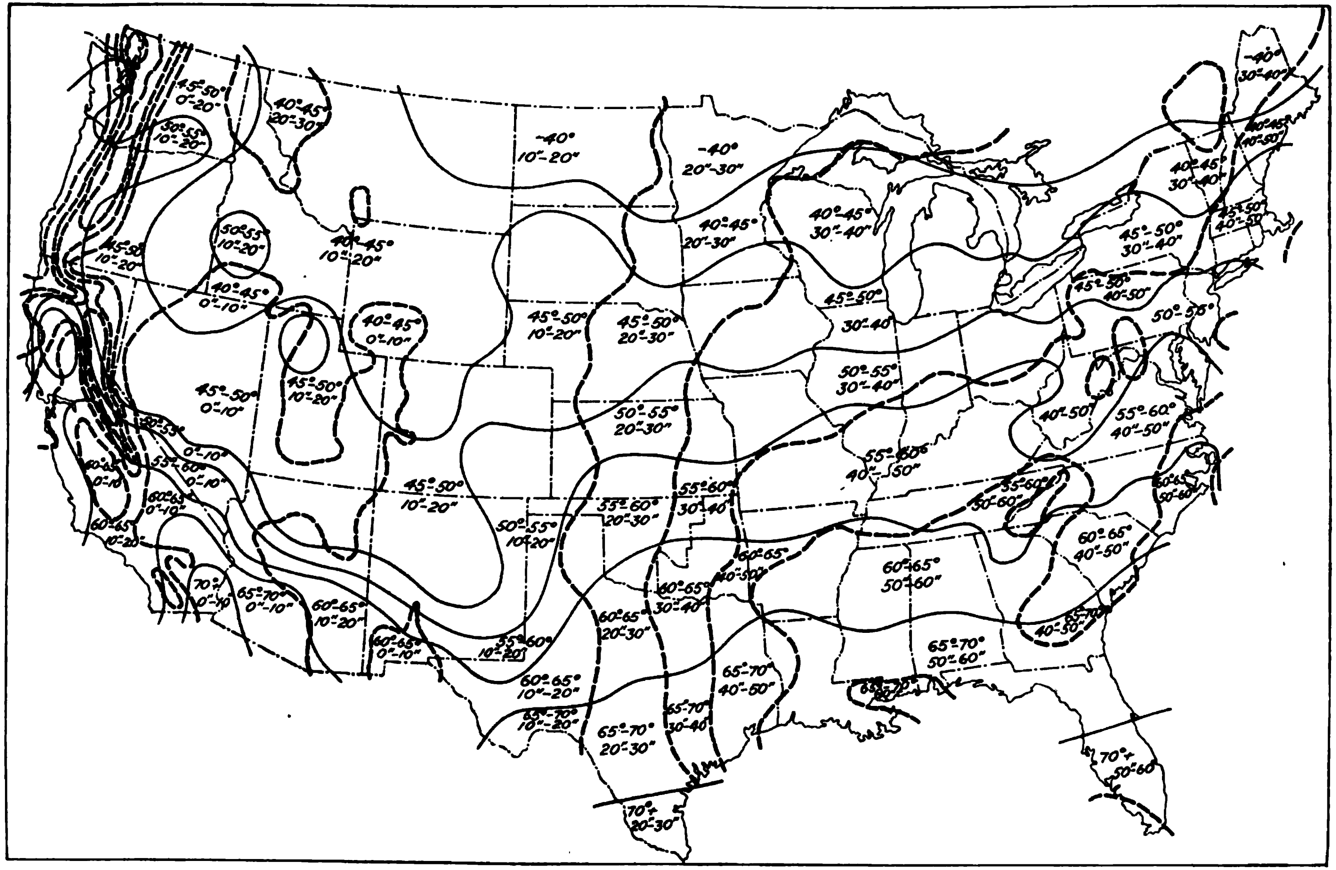
FIG. 4.—Proportionate areas of the United States according to certain limits of precipitation.

Figure 4 shows the proportion of the area covered by each grade of precipitation as compared with the whole area of the United States, represented by the circle, each grade being shown by segments of the circle.

The following table shows the areas having certain normal annual temperatures by steps of 5 degrees Fahrenheit.

Normal annual temperature in the United States, showing percentage of area having normals within certain limits.

Area.	Temperature.	Area.	Temperature.
	Degrees.		*Degrees.*
6 per cent	Below 40	14 per cent	55–60
18 per cent	40–45	13 per cent	60–65
24 per cent	45–50	9 per cent	65–70
14 per cent	50–55	2 per cent	Over 70



SKETCH MAP SHOWING AVERAGE ANNUAL TEMPERATURE AND PRECIPITATION IN THE UNITED STATES.

For example, 24 per cent of the area of the United States has a normal annual temperature of 45° to 50° F. and 13 per cent a normal between 60° and 65° F. Figure 5 shows these facts diagrammatically.

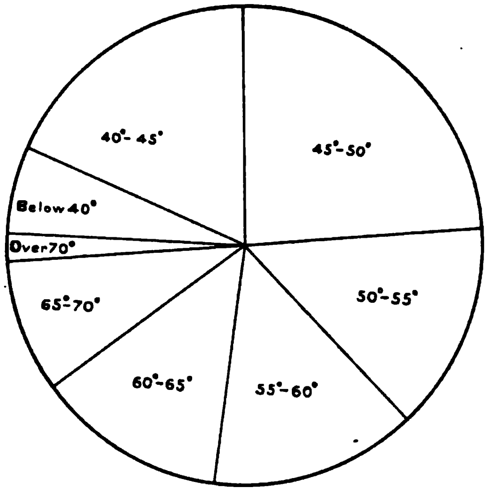


FIG. 5.—Proportionate areas of the United States according to certain limits of mean temperature.

Combining the data in the two tables into a single diagram, in which neither the temperature nor the precipitation is drawn to scale, we get the relations shown in figure 6. From this figure it is seen that with a precipitation of 10 to 20 inches we have in some part of the country all grades of normal temperatures from below 40° to 70° F. and over. With a rainfall of 40 to 50 inches we also have all these variations of temperature. Or looking at the matter from the other side we have a rainfall of over 60 inches, only with a normal temperature of from 45° to 60° F. We have a rainfall of 50 to 60 inches in connection with all temperatures of 45° to over 70° F., and with a rainfall of 30 to 40 inches we have mean temperatures ranging from below 40° to 70° F., but not above. In other words, with these variations of normal annual precipitation, shown for intervals of 10 inches for each grade, and of normal annual temperature with intervals of 5° F., we have 46 combinations of these two simple factors alone, which may influence crop development and may influence the utilization of soils.

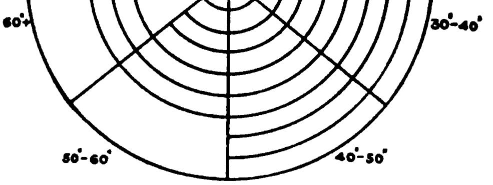


FIG. 6.—Range of temperature in relation to rainfall.

While it is not possible as yet to give an expression to meteorological data which will be a sufficient guide to crop characteristics, it is possible by careful observations of crops and native vegetation to form very accurate estimates of crop possibilities and to define areas in which certain crops having certain qualities can be produced. Such an area as the tobacco area of the Connecticut valley is a case in point; also areas producing sugar beets, sweet corn, and some varieties of fruits. There are special localities where grapes are known to do exceptionally well. The Albemarle pippin, which grows best on one particular soil, takes on its brightest color only when grown on this soil in sheltered coves between certain elevations in the Blue Ridge Mountains.

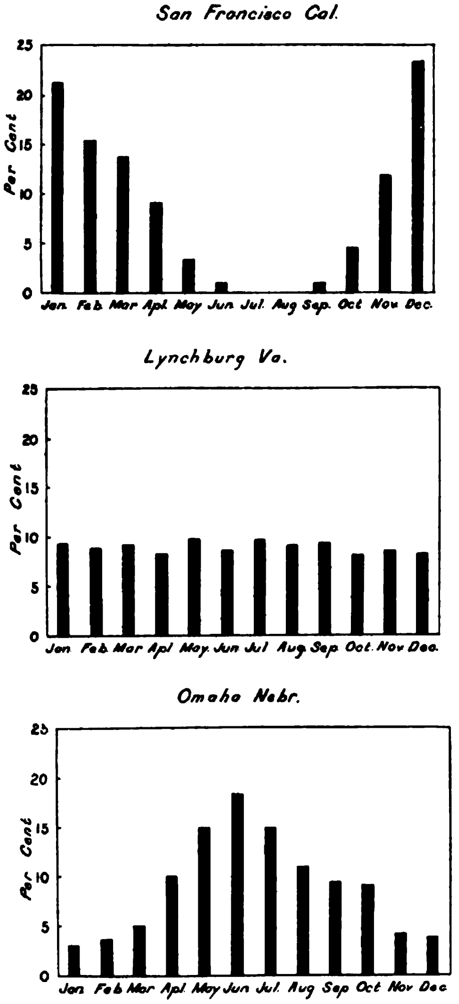


FIG. 7.—Three types of rainfall in the United States.

The differences in climate not only affect the plant directly, but have a great effect upon the soil and its chemical properties or composition—particularly in regard to the chemistry of its organic constituents—making the soil to this extent a different soil and thus affecting the plant.

The following diagram (fig. 7), taken from Weather Bureau records, shows three extreme types of rainfall—that at San Francisco, Cal., where the greatest amount falls in the winter and practically none in the summer months; at Lynchburg, Va., where the amount is quite uniformly distributed throughout the year; and at Omaha, Nebr., where the largest percentage comes in the summer.

THE SOIL RESOURCES OF THE UNITED STATES.

There have been recognized and described by the soil survey in continental United States 715 different types of soil, classified, so far as possible, into series, where the only observable fundamental difference which can not be changed by cultural methods is one of texture and the water-holding power incident thereto, and these again into great soil provinces, in which the materials differ by reason of the divergent forces that have resulted in their formation.

Many of these soil types extend over large areas and under different climatic conditions, and this must be considered in utilizing the soil in any particular line, so that the problem of soil utilization does not seem an easy one. Fortunately, however, we have many reliable guides, as, for instance, the character of the native vegetation, the growing crops, and the experience of farmers, which, together with the methods of study and investigation recently established, make the working out of the principles of utilization for any given soil type and locality far less difficult than it would at first seem.

ADAPTATION OF SOILS TO CROPS.

The principles governing the adaptation of soils to crops may be briefly stated.

The plant must have in the soil and in the atmosphere a congenial and sanitary environment.

The plant is fixed in position in a medium which has previously been occupied by a crop, and which has thrown off waste products.

The sanitation of the soil must provide for the absorption and change to harmless forms of such waste products.

Soils under different climatic conditions, with differences in elevation, slope, drainage, and from certain obscure chemical powers, apart from differences of texture, are able to provide more or less perfectly efficient sanitary conditions for certain crops.

That these differences of adaptation of soils to crops do exist is clearly indicated by the fact that natural plant associations differ for all types of soils which have been encountered, both as to kind of plants and relative numbers of the different species. The prevalence of certain trees or weeds frequently offers safe indications of soil conditions and of crop adaptations. Hilgard lays great stress upon the importance to be ascribed, especially upon virgin lands, to the character of the native vegetation. In our own work the character of the native vegetation frequently affords a very safe guide to the prevalence and amount of alkali salts contained in the soils of any particular locality. Some native plants are not found where the salt content exceeds 0.20 per cent. Other plants are characteristically found where the salt content is very much higher. These indications, however, differ in different places, and, as one would expect, for different types of alkali. It is a well-known fact that cultivated crops differ as regards the amount of alkali—and this varies with the character of alkali—which they can withstand. Alfalfa is exceedingly sensitive. Sorghum and sugar beets, on the other hand, are very resistant. In the development of the tobacco interests in the Miami Valley, Ohio, the sugar maple was taken as a safe indication of the soils on which the best grades of tobacco could be produced.

Perhaps nowhere is the use of character of the native vegetation as a guide to the utilization of soils more marked than in certain areas in Florida. With little or no observable difference in the character of the soils the hammock land, with its luxuriant growth of hardwood trees, is considered the strongest and most reliable land for the general crops of the locality. The high pine land, with its sparse growth of well-developed pine, is second in importance, being adapted, under intensive methods of cultivation, to the production of early truck and vegetables, though rather less valuable for citrus fruits than the hammock land. There are large areas of scrub growth consisting of dwarf and thick-leafed vegetation, frequently surrounded by high pine lands, with no apparent difference in the soil, but these two kinds of native vegetation never intermingle and the scrub land when cleared is not adapted to crops.

We have, on the Eastern Shore of Maryland, land known as the "white oak lands," poorly adapted to corn and even less suitable for other intertillage crops. The white oak is characteristic on this land, not because it grows better on this soil or because it is not found on other soils, but because of the fact that other varieties of oak are seldom found and the white oak is the dominant species. We have the case of the gradual disappearance of the chestnut trees in many areas in the Eastern States and the substitution of other native vegetation. We have very marked instances of the natural rotation of pine and hardwood growth, the soil always being better for agricultural crops following the hardwood than following the pine. Where the sassafras and sorrel come into the soils of the Coastal Plain as a dominant feature of the native vegetation, it is realized that the soil conditions have changed and that the soils are not so well adapted to the ordinary farm crops. Lastly, we have the very striking differences in the native vegetation on the black soils of the Marshall series and the light soils of the Miami series in the Middle West. The former were originally almost exclusively prairie and covered with a heavy growth of native grasses, while the latter carried distinctively a forest cover. There appears to be an incompatibility of association between trees and the grass, and we find characteristically the prairie sod on the one soil and the forest growth on the other, with little or no mingling of the species on the soils of the two series. After cultivation and the working out of the prairie sod trees apparently grow as well on one type of soil as on the other.

Besides pointing out the value of natural vegetation as an indication of the character of the land and showing the advantage which may be taken of the different periods of natural rotation, it is as well to say here that there are certain undesirable plant associations that should never be allowed in the proper utilization of soils. Weeds are almost always injurious to crops in the early stages of growth, as the excreta from the weeds are generally toxic to the plants. In the same way trees are generally injurious to plants in their immediate vicinity, and grass and trees on certain soils react on each other, resulting in the injury and even death of one or the other, while on other soils, and especially with certain trees, grass does very well.

It is seldom safe or desirable to follow a crop with the same crop without resting the soil for a full year, or better still, raising one or more crops of different kinds in the rotation. It is undesirable to use for peaches land from which a peach orchard has recently been removed. Corn, cotton, or tobacco reset after the death of the first plant, if the first plant made any sort of growth, seldom make good plants.

Exceptions may be found to the above statement of the undesirability of continuous use of the soils for one crop. On the Podunk fine sandy loam in the Connecticut Valley tobacco has been grown continuously on some of the fields for twenty-five or thirty years, and it is considered that the quality of the leaf is steadily improving. That the soil can and does adjust itself to the requirements of crops is seen in the case of native vegetation, while the delicacy of the adjustment at times may be seen by the difficulty of reseeding the buffalo grass after the western prairies have been broken up with the plow. The case of the English meadows is another instance of long-continued use of a soil for, in this case, a mixture of plants, with the resultant gradual changes in proportion, although the delicacy of the adjustment is again shown in the infinite care and long time required to establish a perfect sod.

With our annual crops we have the case of the continuous cultivation for many years of cotton, corn, and wheat in certain soils in certain sections, but it is becoming more and more evident that this is neither safe nor judicious, while on many soils in many sections of the country the results have been very disastrous, as the soils have been overloaded with excreta and toxic organic matter until the endurance or the efficiency of the soil has been completely broken down, and the soil, as we say, is worn out.

More striking than these field conditions is the liability of greenhouse soils to break down with the production of large crops in small volumes of soil. With some plants, as, for example, the chrysanthemum, but one crop can be taken, and the soil must then be renewed. No fertilizers or treatment will enable it to produce successfully a second crop immediately. With other crops and with some soils the endurance is longer, but eventually the soil must be renewed to produce the same crop, although fertilizers and manures are used in abundance.

TEXTURE AND STRUCTURE.

Turning now to conditions and properties which are apparent or can be measured, we have first of all the influence of texture. In what we call a soil series, where the material differs only in texture the lighter members of the sandy types, if not too coarse, are adapted to the early spring vegetables, the intermediate loam types are adapted better to wheat, corn, cotton, and general farm crops, under suitable climatic conditions, and the heavy clay types are better for grass and soiling crops for dairying and stock raising. This is general over the eastern half of the United States, but not specific, as there are many modifying influences. For instance, a rather fine sand in a low situation where a more moist condition than usual is maintained produces good yields of wheat. Also, after the intensive fertilization given truck or tobacco a good crop of wheat may be produced on land too light for profitable culture in this crop under general farm methods. It may therefore be given a place in rotation with special crops when it would not be advisable to grow it under less intensive culture given other crops. Also when clover runs out and has to be omitted from the rotation it is often inadvisable to grow wheat on a soil which would otherwise be considered suitable, because the yields can not be maintained without the intervening clover crop.

Corn may often be recommended for a soil not particularly adapted for this crop, because of its value in the rotation and as a necessary feed for farm stock. Such utilization of soils is only justified when other crops equally valuable for forage and grain and better adapted to the soil can not be found.

The structure of the soil as determining the compactness and affecting root penetration and æration, as well as drainage conditions, has much to do with crop adaptation. The crawfish lands of Tennessee are extreme types of soils which run together when wet into an almost impenetrable mass. The so-called mortar beds of Texas, as well as the soils with hardpan underlying, are all examples of undesirable soil conditions, and result in soils that have no general or peculiar adaptation to any of our valuable crops. These conditions can, however, often be relieved or entirely removed by cultural methods. The Susquehanna clay, between Washington and Baltimore, for example, in its natural field condition is very unproductive, but when this is worked up into a granular mass it is as productive as our limestone soils. This improvement can be brought about in the field after long and intelligent working with moderate applications of manure and lime.

Extreme plasticity, as in the black waxy soils of Texas, and the adobe property exhibited by many of the soils of California, affect the utilization of soils, mainly through the methods of management of the soil necessary for profitable crop production.

Drainage conditions, as such, have much to do with soil utilization. Certain crops like rice will produce well only when the soil is submerged with water for considerable periods of their growth, and structure has much to do with ease of flooding and consequently with cost of production. Others, like cranberries and peppermint, will do well in bogs; celery, onions, cabbage, and potatoes do well on muck if properly drained; pineapples grow on the loose beach sand of Florida, which is excessively drained.

It is not unusual to find the character and depth of the subsoil influencing the drainage conditions of a field and affecting the utilization of the soil. This is particularly marked in the case of tobacco in southern Virginia and in North Carolina, where a few inches difference in the depth of the clay subsoil below the surface means the difference between the utilization of the soil for bright leaf cigarette tobacco or the heavy types of export or manufacturing tobacco. Such variations also affect very materially the yield of wheat and other crops, and thus influence the proper utilization of the soil.

Elevation and exposure are important factors in the utilization of soil. Examples of this are seen in the fine quality of grapes on the terraces and slopes in the lake region of New York, Pennsylvania, and Ohio; in the protection from frost and the consequent early maturity of truck crops on the peninsulas of the Atlantic Coast States; in the protection from frost on the foothills and mountain sides. Citrus fruits can not safely be grown upon soils which would otherwise be adapted to them in the San Joaquin Valley, California, but are grown very successfully on the foothills bordering the valley. Peaches are successfully grown on the Maryland-Delaware peninsula and in the mountains of western Maryland, but not with safety on the intervening Piedmont Plateau (although the soils are otherwise well adapted to the fruit), on account of frosts which are liable to occur when the fruit buds are so far advanced as to be easily killed.

A very striking illustration of the effects of elevation and exposure on the possibility of soil utilization is seen in the case of the apple industry of the Appalachian fruit belt. In New York winter apples are commonly grown at an elevation of from 100 to 600 feet above tide. In the Virginia mountains the suitable elevation is not less than 900 or 1,000 feet or more than 2,000 feet, or, say, at an average elevation of 1,500 feet. In North Carolina the elevation for successful and safe crops is a thousand feet higher than in Virginia. Farther south in Alabama the safe elevations are lower than in North Carolina. The finest Albemarle pippin apples are grown on the Porters black loam between 1,000 and 2,000 feet elevation, but only in sheltered coves—not on the exposed sides and tops of the mountains, although the soil may otherwise be well adapted to the fruit. In North Carolina in the lower elevations of the fruit zone the fruit does best in the coves on the north side of the mountains, while at higher elevations it does as well or better in coves with southern exposures.

The color of soils is very often—probably much more often than we realize—an indication of the adaptation of the soil to crops and an index to the proper utilization of the soil. Examples of this are very numerous, and the soil-survey field book of the Bureau of Soils contains a great many miscellaneous soils that can not be correlated with the great series, very often because of differences in crop values which are associated in some way with slight differences in color of soil or subsoil. We never correlate a red soil with a yellow soil, because we know the crop will be different—if not in yield, at least in quality—and, while the crops of the locality may be valued by the quantity grown, we never know when new crops will be introduced in which quality is an important factor. There is, furthermore, a growing tendency to recognize quality in both wheat and corn for different commercial purposes. Quality is a controlling factor in tobacco production and is very important in fruit production.

The red soils of the Orangeburg series of the Coastal Plains are stronger and more lasting under hard usage than the adjacent yellow soils of the Norfolk series. The former will produce more cotton and will stand more continuous culture with the same good treatment. In Alabama and Texas they will produce a cigar-filler leaf of fine aroma, while the Norfolk soils will produce a finer grade of Sumatra wrapper leaf without aroma. What gives the red soil more lasting fertility we do not know. We think it is not directly due to the red iron compounds in the one soil and the yellow iron compounds in the other, but to the conditions or physical forces or chemical properties in the soil, which are able to keep the iron compounds in different conditions of hydration and oxidation in the one case than in the other, which forces appear to play an important part also in the maintenance of proper sanitary conditions in the soils.

The yellow Norfolk soils and black Portsmouth soils are very different in their crop production. The former are adapted to early potatoes, peas, radishes, lettuce, and the lighter spring vegetables; the latter to cabbages and the heavier truck crops. Organic matter added to the Norfolk soils darkens them very little, but when added to the Portsmouth soils makes them still blacker, indicating a difference in the process of decay or in the final stable form of organic matter in the two soils, and affecting in some way their adaptation to crops. Whether this difference in the chemical changes in these soils is associated in any way with the forces which determine the form of the iron compounds in the Norfolk and Orangeburg soils referred to is unknown.

Instances of this kind, where slight differences in shade in the red, yellow, or black soils are associated with differences in yield or quality of crop, at least in certain seasons and under certain conditions of temperature and rainfall, could be multiplied indefinitely. It was a certain peculiar and unusual shade of brown in thin layers in the subsoils of certain soils in Florida which put us on the track of the probable cause of the dieback disease of the orange, which appears to be due to the presence in the soil of a toxic organic compound, which, however, has not yet been isolated or identified.

The peculiar adaptation of soils to special crops has long been recognized. Nowhere is this more strikingly shown than in greenhouse culture, which, where manures and fertilizers are so abundantly and intelligently used, is the last place one would expect to find it. The hothouse lettuce of Boston has long been esteemed the finest product of the kind received in the New York markets. The soil used in the houses is peculiar to the locality. The soils used in the greenhouses around Washington and Alexandria will not produce this fine quality of lettuce, but can and do produce fine violets, with a rich aroma, and these have the highest reputation in the New York and Philadelphia markets. In general, the roses grown in the greenhouses around New York are of the highest rank and are so held in the Boston market, but certain varieties like the American Beauty can not be produced there in the perfection that is attained in the greenhouses of Philadelphia and Washington. So it goes with any greenhouse crop and with each variety of the crop, the soils of certain localities have peculiar advantages, small oftentimes, but with so highly specialized an industry, where quality is so important, enough to give a deserved reputation to the locality and to bring better prices to the grower.

That these differences are real and are associated in large part with the soil and its peculiar adaptation to crops can not be doubted, nor can these peculiarities be entirely overcome by the most skillful greenhouse man. So intense is the cultivation of some of these crops that the soil would appear to be a minor and almost unimportant factor. In the cultivation of the modern varieties of chrysanthemums so much manure is used that the soil seems almost a negligible factor. In addition, the plants are watered with soluble fertilizers up to the very limit of their safe endurance of saline solutions, but after the crop is over the soil must be thrown out, as it is unable to support a second continuous crop of equal quality with the first. Rose soils retain their power of producing fine quality much longer, but with the best care they too have to be thrown away eventually and fresh soils used if the quality is to be maintained. The proper utilization of soils in greenhouse culture and the selection of crops and varieties to be grown is coming to be recognized by the leaders of the industry as of the highest importance.

There is a great field for investigation by soil experts of the cause of this adaptation in these highly specialized industries—a field offering problems which with our modern methods and knowledge it seems possible to solve, and it is perhaps from a study of the conditions surrounding these intensively cultivated forcing crops that the most important light will be thrown upon the general field conditions.

Reference has already been made to the special adaptation of certain soils to certain varieties of tobacco, fruit, and truck crops. It is coming to be realized now that in plant breeding consideration must be given to the character of the soil on which the strains have been produced, as well as to the character of the soil upon which it is proposed to use the selected seed for crop production. Cotton which has been carefully selected until it produces large crops on rich bottom lands will not do so well on sandy uplands. Breeding strains for each of the important types of soils must be by selecting from parent plants which will produce seed adapted to that particular type and its conditions. So far as we now know, this means that the seed should come from soils of the same texture and physical condition. We know this to be true of varieties of wheat and corn, although no general laws have been worked out to explain the wide variations observed in the records of our experiment stations and in the experience of farmers. Breeders of wheat and other crops recognize that some new varieties will be adapted to a wide range of soils and that other new varieties originated on the same soil will prove useful on some soils and will not succeed on others. Before distributing newly bred varieties it is necessary that they be tested on each soil type to which they are to be sent.

SOIL UTILIZATION WORK.

The work of the soil utilization parties of the bureau has been to see, so far as possible, that the soils of the several areas in which they were stationed shall be utilized to the best possible advantage consistent with the local conditions and market facilities and demands.

We should not need to rest the soil any more than we need to rest the atmosphere or the sun. But we do not want to overload or diminish the natural powers of the soil by injudicious methods of cultivation or cropping any more than we want the health-giving powers of the sun and atmosphere obscured by the fumes and smoke of our factories. Whatever may have seemed wise or necessary in the early settlement of the country, when but one or two crops could be grown and marketed, it is no longer necessary, with our vast transportation facilities and ever-growing markets, to overload or abuse the soil by making it produce crops to which it is poorly adapted or in such amounts and at such short intervals that it can not properly digest and take care of the excreta and waste products of the crop before another crop of the same kind is forced upon it.

Furthermore, it is quite probable that some of the soils which we count as unproductive and unsuited to our staple crops, or where the expense of putting them in condition for good yields would not at this time be justified, may be found peculiarly adapted to new crops for food, drugs, or fiber, or plants might be adapted to them by introduction and breeding. This has been the experience in many notable cases; for example, the utilization of the light sands of the Coastal Plains for truck crops, which only twenty-five or thirty years ago were considered, and which were indeed, under the conditions which had prevailed, quite worthless for agricultural crops. Also the utilization of the otherwise valueless coast prairie lands of Louisiana and Texas for rice culture, when a particular variety of rice able to stand the peculiar climatic conditions was found by one of our explorers in Japan. Many other instances could be given to show that much has been done in the profitable utilization of peculiar soil conditions, and it seems quite certain that much more will be done in the future along the same lines.

Much has been done in our laboratory investigations to throw more light upon the complex problem of the fertility and infertility of the soil, and great fields for new lines of work are opening up, based on what has been accomplished. Investigations in these fields will, we think, throw light upon the still more obscure problem of the forces concerned in the adaptation of crops to soil.

The work on the nature of the soil and the conditions affecting fertility has done much to clear up many practical problems and make more certain the proper methods of soil utilization and management. With this knowledge should go extensive knowledge of the soil in different parts of the United States, best gained through active work in the soil survey. With this must go a careful study of the climatic conditions and of the soil in the field as to the texture, color, drainage conditions, depth, and character of subsoil. The elevation and exposure must be considered, and then a very thorough study should be made of the character of the native vegetation, including trees, shrubs, and weeds, and their relative proportions and kind of development. Lastly, the vast experience of farmers must be consulted and the causes of their successes and failures must be studied.

There are, as will be seen by a careful study of the soil descriptions in the latter part of this bulletin, large areas of soils in the United States not now profitably cultivated to crops because they are unsuited to any of our staple crops. Somewhere in the world similar soils under similar conditions may be found adapted to special industries, and our agricultural explorers are finding and sending in plants and seeds which will enable us to take up some of the present waste lands. Much is also being accomplished through the development of irrigation systems, as well as through the reclamation of swamps and overflowed lands adapted after reclamation to special crops of high value, for example, truck crops, peppermint, celery, onions, and the like. We have, however, an apparently even more difficult problem in the utilization of some of our extremely sandy soils or barrens, where the sand is so loose and incoherent, so deep and dry, that none of our present crops are adapted to them. We also have large areas of gravel soils and stony soils that are of little use, although with the same amount of gravel and stones in other soils we can adapt them to very profitable purposes. We also have the extreme types of plastic clays, like the Susquehanna clay, covering large areas, very poorly adapted to any of our common crops, poorly adapted to fruit or forest growth, and which are so costly to improve that they are at present practically useless for profitable agriculture. It would seem that some kind of crop or some industry could be devised for the profitable utilization of these at present useless lands if the problem were conscientiously studied. We also have the utilization of vast areas of cut-over pine lands, and our people have to decide whether these can most profitably go back into forests, or, if they are taken up for agricultural holdings, what crops and what methods of cultivation can be adapted to them? Some of these lands it is known are strong agricultural soils, while others are known to offer such difficulties to the production of economic crops as to make the problem of their adaptation extremely difficult. Taken all in all, the problem of what we had best do with the great soil resources of the country, which becomes apparent upon a careful study of the soil series and miscellaneous types, is one which is well worthy of consideration and of intelligent and systematic investigation.

Some of these series are of small extent and are therefore relatively unimportant from a national standpoint, however important they may be to the States, and particularly to the individuals occupying them as farms. Some of the soil series so far mapped are larger in the aggregate than some of our States and larger than some of the independent countries of the world. The soil experts of the soil survey, making explorations and studies of these soils extending over different parts of the United States, under different climatic conditions and cultural and crop methods, and spending months and years in the study of similar types and series of soils, acquire an expert knowledge of the soils and the possibilities of improving them and our crop conditions which makes their judgment sought for by practical men who desire information as to the chances of success in the introduction of new industries, as to the improvement of existing conditions, and as to the varieties of fruit, truck or field crops that are adapted to certain soil types.

AGRICULTURAL RANK OF SOILS.

The soil type—the unit of soil mapping—may vary greatly throughout its extent in agricultural value, depending upon the proper handling of the soils, the advantage taken of opportunities for special crops, the proximity of markets, and the condition of transportation facilities. These are all factors that are changing from day to day, and the Bureau has never attempted to classify the soils according to their current rank as factors in our agricultural output, but rather to weight them on the basis of their potentiality, no matter whether they were being used to their full capacity, were lying idle, or were still in their virgin state.

Nevertheless, after nine years' work of the soil survey, it would seem that some new facts in regard to the relative importance of the several classes[a] of soils may be brought out by an arrangement of the soils on the basis of their present usefulness, and such a compilation, limited of course to the actual area covered by the soil survey, is summarized in the following table. The table gives the classes of soils, the number of types of soil in each class, the acreage of each class according to agricultural rank, and the total acreage of each class and each rank so far surveyed.

Soils of the United States grouped by classes and present agricultural rank.

Class of soil.	Number of types.	Relative agricultural rank.			Nonagricultural.	Total.
		First rank.	Second rank.	Third rank.		
		Acres.	*Acres.*	*Acres.*	*Acres.*	*Acres.*
Stony loams and clays	45	998,262	710,235	5,000,050	1,664	6,710,211
Shale and slate loams	9	....	100,032	690,126	47,040	837.198
Gravelly loams	62	496,582	315,808	1,650,013	2,752	2,465,155
Sands	48	3,110,178	561,411	2,165,884	....	5,837,473
Fine sands	31	1,840,704	866,770	447,566	....	3,155,040
Sandy loams	74	3,445,691	4,958,165	1,806,421	....	10,209,277
Fine sandy loams	90	6,698,302	4,041,106	736,956	....	11,476,363
Loams	122	6,627,975	2,869,422	1,753,420	....	11,250,817
Silt loams	80	7,353,820	7,307,197	3,811,168	....	18,472,185
Clay loams	68	4,419.385	874,507	629,952	....	5,923.844
Clays	76	6,310,148	1,433,353	2,577,165	....	10,320.666
Unclassified	10	733,203	2.472,215	611,540	3,352,927	7,169,885
Total	715	42,034,250	26,510,220	21,879,261	3,404,383	93,828,114

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[a] The "stony loams," "loams," "silt loams," "clays," etc., each form a class.

The foregoing table shows that the survey has encountered 164 types, amounting in the aggregate to 42,044,241 acres, which may be classed as of the first agricultural rank, 271 types with a total of 26,510,308 acres, of the second rank, and 271 types, with an extent of 21,869,182 acres, which may be considered at present of the third rank. In this grouping it must be borne in mind that the type is considered as a whole, and that an extensive soil, though highly developed in some particular area or areas, would still be classed with soils of lower rank if the greatest proportion of its area was indifferently utilized or used not at all. To take a concrete case, the Dekalb stony loam (area 749,496 acres), is classed with soils of the third agricultural rank, notwithstanding that it is used, in the mountains of Maryland, for instance, in the production of peaches, and is eminently adapted to this crop. The acreage at present in peach orchards is relatively very small, and the great part of the type still undeveloped determines its position in the third rank.

This example brings out clearly some of the problems awaiting solution by the Department. As has been pointed out, soils are not fixed by inherent qualities in the ranks to which their present utilization assigns them. Economic conditions are changing constantly, and these may make of great value soil areas that heretofore had scarcely been considered worth cultivation. The introduction of bright yellow tobacco in North Carolina, for instance, increased the price of the sandy lands tenfold. Some of the sandy types, which thirty or forty years ago would have been classed as of low rank, have by special adaptation to truck growing been changed during the last generation to a position of the highest rank. Similarly, by reason of special adaptation, some of the stony loams and clays have passed from the lower to the higher ranks. Some of this progress will come inevitably as the result of increasing rural settlement and the growth of urban population and markets; but one of the most promising fields for work that the Department has to-day is the field of research to discover special crop adaptations for the soils at present ranking as inferior factors in our agricultural economy, and thus to raise these soils to positions of greater utility. The most potent agencies working to this end will always be the selection of new crops and the aiding and fostering of new industries, though of only less importance is the question of soil improvement. The problem resolves itself into two broad divisions—the extension of established industries on soils of known high value for certain crops, and—a more difficult matter—the utilization of soils of unknown adaptations or perhaps of inherent qualities adverse to profitable cultivation.

FERTILIZERS AND MANURES.

The reason for the beneficial effect of fertilizers has long been held to be due to the supplying of mineral plant food to the soil in a more soluble or available form than is found in soils of low productive capacity. There are three great facts which have never been satisfactorily explained under this hypothesis: (*a*) Stable manure as a rule has a much higher fertilizer value than would be indicated by the amount of mineral plant food elements it contains. (*b*) Plants contain usually as much, or more, of silica, iron, aluminum, magnesium, and sodium as of nitrogen, potash, phosphoric acid, or lime, and the former group are as necessary to plant life and are quite as insoluble in their soil compounds as the latter; they are rarely used successfully as fertilizers, and they are not considered commercially as being in the class of plant foods. (*c*) Certain nonplant food substances, such as copper sulphate, ferrous sulphate, common salt, and some three or four hundred substances which have been tried from time to time do give occasionally very beneficial results. However, it is not always possible to explain any fact by hypothesis, however broad we make it, and as we know that nitrogen, potash, and phosphoric acid are essential elements of plants, and as we often get bigger yields after applying substances containing them to the soil, we have come to look upon the question as proved that they act solely or principally through feeding the plant.

Another fact which we have known for a long time and which we have not been able satisfactorily to explain is that dwarfed plants or plants on infertile soils often contain a larger percentage of ash than better plants grown on more productive soils. This would indicate that on such poor soils they are able to take up more potash, phosphoric acid, and lime than they are able to elaborate into good plant tissue.

The most advanced scientific work now shows that fertilizers have another and an important function in keeping the soil sweet and sanitary for the plants.

The natural supply of mineral plant food comes directly from the solution of the mineral particles of the soil. The solubility of these minerals gives a very dilute solution, but adequate in amount and rapidity of solution for the need of field crops. Furthermore, the soil has a great absorbent power, and soluble fertilizer minerals applied to the soil do not long remain in the free or capillary water in which plants are supposed to feed. That is, when a soluble phosphate salt is added to a soil in the usual amount, or even in much greater amount than is ordinarily applied, it can not again be obtained by simply washing the soil, as it is withdrawn from the solution and firmly held by the surface of the solid grains, and the soil moisture is not sensibly enriched by the application.

It has been shown that another cause of the low yields, in cases where the physical conditions of the soil are satisfactory, is the presence in the soil of toxic organic substances resulting in part from crops which have previously occupied the land, and very frequently through neglect of proper methods of tillage. A number of these toxic compounds have now been separated from the soil, identified, and their properties studied. These are rather instable compounds under certain soil conditions. That is, they can be rather easily oxidized or broken down into other bodies usually much less toxic or even beneficial, and often this oxidization or decomposition takes place more easily if readily decomposable organic matter like stable manure be placed in contact with them.

The infertility due to one of these toxic compounds of a soil is transmitted to an extract of the soil (water which has saturated the soil), and if seedling plants be grown in such an infertile extract the growth can be markedly improved in a number of ways: (*a*) By adding certain fertilizer salts; (*b*) by easily oxidizable organic matter like pyrogallol; (*c*) by absorbing substances like carbon black, absorbent cotton, or shredded filter paper; (*d*) by simple boiling, and (*e*) by diluting the soil extract with pure distilled water. The effect of increasing the vegetative growth shared in common by these agents can not be ascribed to the power of actually feeding the plant, for this power is possessed by only one of them.

The first and immediate effects of fertilizers is sometimes deleterious. Even if nitrate of soda be added to a soil which is known to respond to this fertilizer and an extract be made of the soil immediately after adding the fertilizer this extract may not be as beneficial as the extract of the unfertilized soil, while if the nitrate had been allowed to act on the soil for several days before the extract had been taken it would have been much improved.

The same thing has been observed with soluble phosphates, that is, that it takes an appreciable time for the beneficial results to appear and the first effect is often deleterious. This is even more pronounced in the case of green manure, which must have a certain time to act on the soil before it it safe for plants, although this is usually only a matter of a few days. When nitrates are added to infertile extracts and plants grown therein they often disappear entirely from the solution before their full beneficial effect is felt, as shown by the increased growth of the second crop of plants in the same solution from which the nitrates had been removed by the first crop.

Fertilizers destroy or change known toxic bodies, sometimes by combining with them to make salts which are nontoxic or beneficial and sometimes by actually increasing the rate at which the toxic organic bodies are oxidized, so that the most delicate chemical tests fail to show a trace of the organic substance that was present before the fertilizer was added. Very often plants themselves destroy the toxic material, and plants and fertilizers together often act much quicker and more effectively than either alone.

There is evidence, therefore, that the fertilizers do something to the soil to put it into better condition for crops. In disappearing the fertilizers have performed some function, have acted on some constituent of the soil that had heretofore retarded the growth of plants, and, by its removal, oxidation, or other change, have rendered the soil a better medium for the growth of the plant.

The results of fertilizer plot tests, along which lines a vast amount of work has been done, and the experience of farmers seem to indicate that in a majority of cases nitrates increase vegetative growth of plants; phosphates tend rather to check this vegetative growth or to produce relatively more seed, while potash appears to promote starch-forming activities (develop tubers in potatoes) and to improve the quality of fruits (for example, apples). Combinations of these elements often seem to show in their effect the results which would be expected from each alone, that is to say, a mixture of nitrogen and phosphorus may increase the vegetative growth and also increase the amount of grain produced on the wheat plant. By adjusting the proportion of these elements it has doubtless been possible in many cases to modify the crop within limits as desired. So, in the same way, with potatoes, a moderate supply of nitrogen, either in the form of nitrate of soda or of organic matter, in conjunction with potash, often produces an increased growth of vine necessary for an increased development of tuber.

Another fact which must be borne in mind in any fundamental study of fertilizer effects is that these effects are greatly influenced by weather conditions. It is a common experience that a brand of fertilizer or a single fertilizer constituent which has a decidedly beneficial effect this year may have little or no effect on the same soil and the same crop another year when the weather conditions are markedly different. It is this variation which makes fertilizer practice so uncertain. It is inexplicable from the plant-food idea. But if we view the soil as a receptacle for plant excreta and organic remains which in certain forms may be harmful to succeeding crops, and that this organic débris must, in order to render the soil safe for plants, decay, through oxidation or otherwise, to those products which we recognize, broadly, as humus bodies, then we may readily understand that the temperature, humidity (of both air and soil), and even sunshine and wind, may modify the process through which this decay goes on to such an extent as to change the intermediate bodies which may be formed. In the decay of the organic matter through fermentation or otherwise, not one but many intermediate bodies are formed, some of which may be beneficial and others may be more or less deleterious to crops and each having different characteristic properties and reactions with mineral salts. In other words, if we look upon the cultivation of the soil as a method to promote fermentation for the purpose of facilitating certain necessary organic changes and of rendering the soil suitable and sanitary for a subsequent crop, then we may expect an influence of climate on fertilizer effects, as we would have different intermediate decomposition products formed in the breaking down of the organic matter under different moisture and temperature conditions.

We have learned, furthermore, from the experience of farmers and from the more exact methods of plat and pot culture, that different combinations of the different plant-food constituents have different effects upon the crop. For example, the different salts of potassium, the different forms of nitrogen in mineral salts and in organic material, and the different forms of phosphorus have different effects on different soils, with different crops, and in different seasons. It is easy to show that it is the substance rather than the element, for the same plant-food element may be in compounds which are more or less beneficial or in other compounds which produce very unfavorable conditions in the soil, rendering them more toxic for plant growth.

Such in a broad way is our present state of knowledge in regard to the principles of fertilizer effects on soil fertility.

The Bureau of Soils has made a thorough comparative investigation of the fertilizer and manurial requirements of several hundred samples of soils from various parts of the United States, under as nearly as possible the same climatic conditions. These investigations show that fertilizers are relatively more effective on light than on heavy soils; also that they give, as would be expected, the greatest relative effect on poor soils rather than on rich soils, when both are put in good physical condition.

The results with commercial fertilizers, or rather with the mineral salts ordinarily found in commercial fertilizers, show in about 29 per cent of the cases that the elements are nearly interchangeable—that is, that nearly equal effects are obtained with common fertilizer salts containing potassium or nitrogen or phosphorus. About 11 per cent of the cases show that when two or more elements are used together the resultant increase in the crop is greater than the sum of the increase obtained by each of the elements used separately on other samples of the soil. Lastly, it is shown that in about 60 per cent of the cases the sum of the increase in growth due to each fertilizer constituent when used alone is greater than the increase obtained from a mixture of the fertilizer constituents applied to a separate sample of the soil, although the mixture gives a larger absolute increase than any one of the ingredients composing it when used alone.

Comparing, now, the relative efficiency of mineral fertilizers and organic manures, it is found that the number of cases where the greatest increase is obtained from the organic manures is far in excess of the cases where the mineral fertilizers have given the largest increase in plant growth. The actual results of this work showing the number of cases where organic manure or complete mineral fertilizers have given the greatest increase in yield are as follows:

	Per cent.
Manure	38
Cowpeas and lime	38
Complete mineral fertilizer and lime	20
Complete mineral fertilizer alone	4
Total	100

It would seem from this that for the greater number of soils the most efficient fertilizers of the future will be of organic rather than mineral origin, provided that when such a substance is found it can be obtained in sufficient quantity and at a sufficiently low cost and be at the same time less bulky to ship than stable manure.

There is a general feeling, although this does not seem to be borne out in practice, that both nitrate of soda and potash are more efficient in moderately cool climates and phosphates and organic nitrogen in warmer climates. The Bureau's comparative study under similar climatic conditions indicates that on the soils of the North Central States manure is about three times as efficient as mineral fertilizers.

In the soils of the Atlantic and Gulf States manure and green manure are about equally as effective as mineral fertilizers. It must not be forgotten that on certain soils, either under field conditions or in pots, manure appears to be deleterious and on some soils mineral fertilizers likewise appear to be deleterious, although the cases where either of these extreme results occur are very rare.

It has been shown by the investigations of the Bureau and also by others that the beneficial effect of stable manure is due principally to the organic constituents of the manure rather than to the mineral salts which it contains. We know, too, that the same food passing through a man, horse, cow, pig, or poultry gives, with the same mineral constituents, manures of very different properties and values, because of the difference in the character of the organic constituents resulting from the differences in the digestive processes and metabolic processes in the animals through which the food has passed.

In the case of horse manure we also know that it is advisable, and for some soils, as well as for some plants, necessary, to give the manure a preliminary fermentation before it is applied to the soil. In other words, on some soils we can safely use fresh manure and even have it contain a great deal of coarse litter, while on other soils we can safely use only well-fermented manure in which even the litter originally present has lost its form and has become well broken down. Straw as such is often deleterious when applied directly to the soil and turned under, but straw mixed with manure and partly fermented in the manure pile is beneficial to most soils, indicating a difference in the way decomposition proceeds, whether this starts directly in the soil or in the manure pile.

Of the organic matters used directly or indirectly as manure, the most effective are those containing a large proportion of nitrogenous bodies. The leguminous plants are the most effective as green manure and the manure from a grain-fed horse is more effective than from a horse fed principally hay or on pasture. The protein bodies are as a rule very complex and break down through oxidation, fermentation, and the action of enzymes or bacteria into bodies many of which are now known to be beneficial or detrimental to plants. The same original substance may break down into beneficial or detrimental substances, according to the agencies acting on it and the conditions under which they act. Fresh pea vines and pea-vine hay may, and usually do, give very different results when applied to any particular soil. Ground wheat seed and germinating wheat seed have very different effects upon the soil. So it is evidently not the nitrogen, but the compound, which determines the action on the soil.

It is generally believed that the beneficial effect of nitrogenous fertilizers is due to nitrification, through bacterial action, with the ultimate formation of nitrates, and this is undoubtedly important, not so much because of the nitrates formed, but because decomposition proceeding in that way is generally more beneficial than if it proceeds in other ways when other less beneficial intermediate products may be formed.

These nitrogenous bodies have a direct effect on soil conditions, making the soil either better or worse for plant growth. Some of the toxic bodies which have been separated from the infertile soils in our laboratories are nitrogenous bodies.

Coming now to a consideration of the commercial fertilizers, which are being used by our farmers to the extent of probably $80,000,000 or $100,000,000 annually, it is apparent that the nature of the substance containing the plant-food element is quite as important in judging of the efficiency of a fertilizer for any particular soil or crop as is the actual percentage of the element present.

The substances commonly used as carriers of phosporus in commercial fertilizers are the southern phosphate rock, ground bone, bone meal, boneblack, acid phosphate, reverted phosphate, floats, Thomas slag, and redondo phosphates.

The substances commonly used as carriers of nitrogen are nitrate of soda, sulphate of ammonia, cotton-seed meal, dried blood, tankage, fish scrap, guano, and castor pomace. Other nitrogenous substances, like horn, hair, feathers, and wool waste, are prohibited by the laws of many States from being incorporated into commercial fertilizers, as they are not considered good substances for fertilizer use, although they are highly nitrogenous.[a]

The substances commonly used as carriers of potassium are kainit, muriate of potash, sulphate of potash, and carbonate of potash. There are other potash salts, as, for example, iodide of potash and chlorate of potash, which are harmful and could not be used in fertilizers even if they could be obtained cheaply enough.

It is the experience of farmers and of investigators generally that these different carriers of phosphorus, of nitrogen, and of potash act differently on different soils and in different seasons and with different crops—that is, that raw rock phosphate, ground bones, boneblack, acid phosphate, floats, and slag are different substances which may act differently on different soils with different crops and with different seasons. Likewise that nitrate of soda, sulphate of ammonia, cotton-seed meal, dried blood, fish scrap, and guano are different substances in an agricultural as well as in a commercial sense, and this in addition to their differences in nitrogen content.

Most tobacco growers and many truck and fruit growers recognize a difference in the agricultural value of kainit, muriate, sulphate, and carbonate of potash as influencing the quality if not the yield of their crops. It is true that no definite law has ever been worked out even for a particular field, but this is probably due in large measure to a lack of knowledge of how these substances act and the influences which control their action on the soil.

It seems entirely probable that in the future we will require to know in buying commercial fertilizers not only the percentage composition of plant-food constituents, but the nature of the substances containing them. This would presuppose that the farmer knew whether nitrate of soda, cotton-seed meal, or dried blood would give the better results on his soil and for the crop he proposes to grow—a fact which it is not difficult to imagine he could determine for himself within limits with the wire-pot method devised and described by the Bureau of Soils.

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[a] The Kansas law requires a guaranty from the manufacturer or seller desiring to register a brand of fertilizer for sale in the State that the "fertilizer contains no horn, hoof, hair, feathers, or other similarly inert nitrogenous matter," and requires the manufacturer or seller to "state the sources of the constituents of the brand of fertilizer offered for registration, which statement and the information contained therein shall be recorded for reference, and shall not be disclosed by the State director unless the materials used are such as are liable to lower the standard of the fertilizer or give it deleterious properties."

Everyone who has given any thought to the matter realizes the woeful confusion and lack of intelligent control there is in our fertilizer practice. This is due solely to our lack of knowledge of the real functions of fertilizers. We buy what is offered to us on a basis of the percentage of potash, nitrogen, and phosphoric acid, without a knowledge of the character of the ingredients. The manufacturer and dealer offer us the best they can, and their goods are nearly always up to the guaranty so far as plant-food elements are concerned, but neither the manufacturer knows, nor do we who make the purchase know, what carrier the element should be in to suit our particular needs. If we did know the manufacturer would only be too glad to furnish the actual kind of material needed for our soil and crop. It would cost him no more in the long run and would be better business and give more satisfaction all around.

The experience of farmers and the results of scientific investigation show that both the material and the proportion of the different materials in a mixed fertilizer may have an important influence on the results for any particular soil, so that it would seem highly important that each brand of fertilizer should have a guarantee as to the kind and amount of each ingredient in which the desirable plant-food ingredient is carried. We already know some of the principles which should guide us in the selection of materials for some of our soils and crops, and it does not seem impossible for us to extend our knowledge greatly along these lines, now that we are beginning to comprehend the problem and the function and the mode of action of fertilizers.

To show how hopelessly confused our fertilizer practice is at present and the great need for straightening the matter out, let us carefully analyze the situation in a single State, as contained in an official report of the North Carolina department of agriculture for the year 1907. There were 1,575 brands of fertilizers registered under the law for sale in the State. These were accredited to 113 manufacturers, and practically all of them came up to the guarantees so far as the plant-food elements were concerned. Considering the guarantees as correct, 720 brands, or 52 per cent, contained 8 per cent of phosphoric acid; 96 brands, or 7 per cent, contained 9 per cent of phosphoric acid; and 203 brands, or 15 per cent, contained 10 per cent of phosphoric acid. About 75 per cent of the brands, therefore, contained from 8 to 10 per cent of phosphoric acid.

There were 505 brands, or 54 per cent, containing 2 per cent of ammonia; 229 brands, or 24 per cent, containing 3 per cent of ammonia; and 103 brands, or 11 per cent, containing 4 per cent of ammonia. That is, about 90 per cent of all mixtures containing ammonia had from 2 to 4 per cent of this substance.

Of the mixtures containing potash, 445 brands, or 37 per cent, contained 2 per cent; 266 brands, or 22 per cent, contained 3 per cent; and 180 brands, or 15 per cent, contained 4 per cent of potash. That is, about 75 per cent of the mixtures containing potash contained from 2 to 4 per cent of this substance.

It will be seen, therefore, that in a large proportion of the mixtures the amount of the plant-food elements varied only 2 parts in 100—a rather small variation in fact—but we must remember there is also possibly a large, although entirely unknown, variation in the nature and possible efficiency of the compounds or substances carrying the element.

Considering now the complete fertilizers containing all three of the plant-food elements, of which there were 962 brands registered, it appears that there were 245 brands, or 25 per cent, which had the formula 8–2–2 per cent of phosphoric acid, ammonia, and potash, respectively; 134 brands, or 14 per cent, with the formula 8–3–3; and 33 brands, or 3 per cent, with the formula 8–4–4, or 412 brands, or 42 per cent, made up of these three simple formulæ. Do the 245 brands of the formula 8–2–2 really represent different fertilizers having differences which are apparent on different soils? Doubtless they do, for it is not only apparent from the figures given, but it is an actual fact that some of the manufacturers put out a number of brands under different trade names having the same formula, so far as the guaranty shows. Furthermore, it is the experience of farmers that these brands do differ in their effects on the soil. If these differences do exist, it must be due to differences in the materials used or in the way they are prepared and mixed.

It is important, therefore, that the substances used in the preparation of the fertilizers be stated by the manufacturer and be guaranteed in some way, so that each farmer may know exactly what substances he is buying in purchasing mixed fertilizers.

The uncertainty in our fertilizer practice is more fully exemplified in the formulæ presented to us by the manufacturers of fertilizers for the growing of special crops, which is, of course, the highest test of fertilizer production and which should give from experience and study the most exact knowledge.

There were 144 registered brands for tobacco in the North Carolina report. In these phosphoric acid ranged from 4 to 9 per cent, ammonia from 2 to 5 per cent, and potash from 2 to 10 per cent—very wide variations it must be admitted. Seventy-seven of these brands had the following formulæ:

30 brands, or 20 per cent	8–2–2
19 brands, or 13 per cent	8–2–3
43 brands, or 30 per cent	8–3–3
11 brands, or 8 per cent	9–2–2
8 brands, or 6 per cent	9–3–3

There were 79 special brands for cotton. In this list the phosphoric acid content ranged from 8 to 10 per cent, ammonia from 2 to 4 per cent, and potash from 1 to 4 per cent. Eighty-four per cent of the brands had the following four formulæ:

10 brands, or 13 per cent	8-2-1
29 brands, or 37 per cent	8-2-2
17 brands, or 21 per cent	8-3-3
10 brands, or 13 per cent	9-2-2

The variation in composition of the special brands recommended for truck, potatoes, grain, and corn is so great that they can not be grouped in any orderly way, under a few heads, as the above. The results, therefore, are given in the following tables, in which the first column indicates the percentage composition and the other columns the number of brands containing the different plant-food elements corresponding to the percentage shown in the first column.

There are 105 brands especially recommended for truck, as follows:

Per cent.	Phosphoric acid, No.	Ammonia, No.	Potash, No.
2	....	5	4
3	....	7	11
4	2	19	14
5	8	35	37
6	26	5	6
7	34	23	20
8	32	1	9
9	....	....	1
10	1	10	4

There are 63 special brands for potatoes, as follows:

Per cent.	Phosphoric acid, No.	Ammonia, No.	Potash, No.
1	....	....	1
2	....	11	1
3	1	4	5
4	2	7	5
5	4	21	16
6	20	2	6
7	18	16	20
8	15	....	5
10	2	....	4

There are 53 special brands for grain, as follows:

Per cent.	Phosphoric acid, No.	Ammonia, No.	Potash, No.
1	....	....	3
2	....	13	23
3	....	2	6
4	....	....	20
7	....	....	1
8	24	....	....
9	1	....	....
10	25	....	....
11	1	....	....
12	1	....	....

There are 9 special brands for corn, as follows:

Per cent.	Phosphoric Acid, No.	Ammonia, No.	Potash, No.
2	....	4	7
3	....	1	1
7	....	....	1
8	5	....	....
10	4	....	....

How can the farmers select with judgment the fertilizer suited to their own particular farms from the 1,575 brands offered for sale in the State of North Carolina? It requires no words of comment to show the need of a thorough investigation on this subject.

It will be remembered that from the investigations of the Bureau of Soils only 4 per cent of the soils examined gave the highest increase of growth with chemicals, the other 96 per cent giving better results with manure and cowpeas, and yet our farmers are spending in the neighborhood of $100,000,000 for commercial fertilizers made up in large part of mineral substances.

The investigations of the Bureau of Soils indicate that the fertilizer requirements do not follow, except in a most general way, the great soil types, but depend more upon the cultivation and previous cropping of the soil, so that it is a problem of the farmer or of the larger community where similar practices prevail.

Knowing as we now do that the fertility of the soil is largely influenced by the cultivation the soil has received and by the previous cropping, which leaves the soil in a more or less unsanitary condition, the investigation should be extended to certain typical soil conditions, which should be tested to show efficiency of each fertilizer substance and various combinations of them for such crops as it is proposed to grow. There seems no better way to carry on the preliminary investigations than with the wire-pot method devised by the Bureau of Soils, and there could well be cooperation in this work between the farmers and the experiment stations and the Bureau of Soils in an earnest endeavor to straighten out this large and important subject.

The method for determining the fertilizer requirements with wire pots is simple and direct, as the effects of treatment are shown by the plants themselves; but the taking of samples of soil requires judgment, as every spot where the small sample is taken, as well as the time of year or character of the season when the sample is taken, may influence the result. The sample should be taken at as near as possible the time when fertilizers are to be applied to the field and should be tested before it has had time to dry out. This throws the work all into a very short space of time in the very busiest part of the year. The ultimate and only really conclusive test, however, of the fertilizer requirements of any particular soil is the actual field test on the farm or on a small plot, and a number of State experiment stations and State departments of agriculture, among them the North Carolina department of agriculture, realizing the importance of this matter, have inaugurated a very wise system of test farms, located on the important soil types of the State.

SOME FACTORS IN CROP ROTATION.

The benefit derived from a suitable rotation of crops in maintaining the fertility of the soil has been known and has been commented on from the earliest historical times.[a] The first serious consideration of the reason for this seems to have been given by De Candolle, who reached the conclusion or announced the opinion that the deterioration of soils seen in the continuous cultivation of the same crop was due to a poison which the plant excreted and which, accumulating in the soil, made the conditions less comfortable for succeeding crops of the same kind, but was without such toxic effects toward plants of a different order. Liebig at first thought that this was the only scientific explanation that could be adduced for the beneficial effects of rotation. Later, after working out his mineral theory of plant growth, he gave as his conclusion that plants distort the ratio of plant food and so effect their gradual starvation, unless time is given for the soils to weather or another crop with different plant-food requirements is grown on the soil in rotation to restore the proper balance in the ratio for the first crop.

Without entering into the evidence which can be adduced to show the insufficiency of Liebig's views, it will suffice to say that no direct proof of Liebig's contention has ever been presented. De Candolle's hypothesis has been exhaustively investigated, and there is no reason to doubt that organic substances are excreted by plants or formed by bacteria associated with specific crops which do become toxic under certain soil conditions.

It is always permissible and generally easier in a scientific investigation to work from the most pronounced cases, where the phenomena are usually more easily found and less liable to be masked by other conditions which may or may not be effective.

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[a] A. B. Griffith states in "A Treatise on Manures," third edition, page 3, that twenty-eight years after the publication of Sir Anthony Fitzherbert's "Ye Boke of Husbandrie," the earliest English work (1534) of any importance on agriculture, Martin Tusser published his famous "Five Hundred Points of Husbandrie," in which he strongly recommends the rotation of crops. He says:

> "Oates, rie or else barlie, and wheat that is gray,
> Brings land out of comfort, and soone to decay:
> One after another, no comfort betweene
> Is crop upon crop, as will quickly be seene,
> Still crop upon crop many farmers do take,
> And reape little profit for greedinesse sake."

Such marked conditions of the rapid decline of soil fertility are by no means uncommon in field experience. On certain recently reclaimed muck soils of northern Illinois, Michigan, and Wisconsin corn produces bountiful yields the first year. With two or three successive crops of corn without manurial treatment the yield decreases until it is no longer profitable to grow corn on these soils. It has indeed been found that with abundant applications of stable manure or certain potash salts this rapid deterioration may be prevented or the soils which have lost their power of producing profitable crops can be restored. On such virgin soils it is inconceivable that a crop or two of corn can either exhaust the potash or can so change the ratio of plant food as to cause this notable decrease in soil fertility.

On the reclaimed peat lands of the Stockton area, California, potatoes give a yield of upward of 400 bushels per acre for the first crop. In two or three years' continuous cultivation to potatoes the yield is reduced to about 40 bushels per acre, although the fertility as regards barley has not been noticeably affected. It is a very common experience with flax growers throughout the world that flax is a very exhausting crop for the soil and that satisfactory crops can not be maintained for more than two or three years upon soils continuously cultivated to this crop, but that a flax-sick soil is not sensibly impaired for wheat or other crops than flax.

Throughout the Eastern States, as well as in many of the countries of northern Europe, clover-sick soils are common where, without any apparent disease in the crop, clover refuses longer to grow under the usual methods of cultivation. Such clover-sick soils are not noticeably injured for other crops to which the soil is adapted, except through the absence of a leguminous crop in the usual rotation.

The deterioration of certain lands when continuously cropped to wheat, cowpeas, cotton, or to some of the truck crops, without systems of rotation or special treatment of the soil, is so well known and so often experienced as to make it unnecessary to cite specific cases.

Coming now to the results of laboratory investigations of this subject, it has been possible by growing successive crops of wheat in paraffin wire baskets until wheat will no longer grow upon the soil, or by growing wheat in pure nonnutrient agar jelly, to show that the plant excretes a crystalline organic body of known composition which was not present in the soil or in the agar before the wheat plants had grown in them. This organic body, when added to a culture medium, is toxic to wheat, but not toxic to cowpeas.

From a cowpea-sick soil produced by the continuous growth of cowpeas, under greenhouse conditions, has been obtained a pure crystalline organic body, not present in the soil before cropping, which is exceedingly toxic to cowpeas when mixed in otherwise good culture medium, but is not so toxic to wheat.

After the wheat has grown on the cowpea-sick soils and has been unharmed or even benefited by the previous cowpea growth, cowpeas can be again grown, and they in turn will be found to benefit by the activities of the wheat. Several organic bodies have been isolated from soils, some of them phosphorus compounds, nitrogen compounds, sulphur compounds, waxy and fatty bodies, so that a very wide range of organic bodies likely to result from metabolic changes and from soil conditions may be expected from further investigations of the chemistry of the organic matter of the soil. Whether these bodies are specific for each kind of plant we do not know, but it seems probable that either in the metabolic processes of the plant or from the changing conditions in the soil and climate they offer marked differences which will have to be further investigated.

It is very certain also that in many soils these bodies do not persist for any great length of time. They are all likely to change through oxidation and fermentation into intermediate toxic or nontoxic bodies, and finally, under the very best soil conditions, into inert black humus bodies. Some of these organic bodies, at least under certain soil conditions, appear to be stable for a great length of time, as we have infertile soils which have not been productive within the memory of man. Some of these organic bodies seem to be toxic to all of our cultivated crops. Many of them appear to be less toxic to some crops than to others or even beneficial to some crops.

With substances of the first class, which appear to be toxic to all crops, it will be necessary to remove or destroy them before the productivity of the soil can be renewed. With bodies of the second class, especially such as are beneficial to some plants, the object should not be to destroy unnecessarily, but to benefit by their presence by the growing in rotation of such crops as the conditions would seem to be adapted to. In the change or destruction of these organic bodies the first principle of soil management, viz, the cultivation of the soil is the most important, as, aiding in fermentation, it induces changes which as a rule are highly beneficial.

The breaking down of these organic bodies through fermentation brought about by cultivation of the soil is usually markedly hastened by an application of easily decomposing material like stable manure or green manure, for in the process of decay of this very unstable material the destruction of the more stable forms of organic matter in the soil is facilitated. Less efficient, but still very important and often more economical, agencies in the destruction of the organic bodies—of the changing of the toxic into nontoxic forms—are found in the commercial fertilizers. Some of these fertilizer effects are now fairly well understood, but a great amount of research yet remains to be done before this subject of fertilization will be sufficiently well understood to make the practice much more sure and more economical than it is at present. It is now known that, at least under certain conditions which have been studied, fertilizers and crops together may do more than either by themselves, and that certain fertilizers may have their place in the crop rotation. This accords with experience, which has shown that fertilizers give better results with some crops than with others in the rotation system.

It is not presumed that the principles of crop rotation can yet be worked out in a scientific manner for all crops, or under all soil and climatic conditions, but enough has been given in this rapid sketch of some of the principles of rotation, brought out in the course of our investigations, to show a wide field of inquiry. With further work along this line, using methods now being developed, the real principles of crop rotation can probably be worked out.

FACTS REGARDING SOIL DETERIORATION.

There are in the United States soils which, so far as known and within historic times, have never been productive, although under climatic conditions favorable for crops. Besides some of the very dry coarse sands and gravel we have as examples the Elmwood loam of Connecticut, the Conowingo loam of North Carolina, the Monroe silt loam of Louisiana, and the scrub lands of Florida. Other soils are noted for their great and lasting fertility. Examples of this class are the Dunkirk soils of New York, the Hagerstown soils of Pennsylvania, Maryland, and the Valley of Virginia, and of the blue-grass region of Kentucky, the Marshall soils of Iowa, the Houston soils of Alabama, and the Yazoo soils of the Mississippi Valley. Other soils, again, forming an intermediate class, originally very productive, have deteriorated in yield until they are now relatively unproductive. Notable among these are the Cecil soils of Virginia, North Carolina, South Carolina, and Georgia, some of the Norfolk soils of Maryland and Virginia, and the Portsmouth silt loam of North Carolina. It has been the general custom in some parts of the country to crop fields in single crops until they become so unproductive that they are abandoned to forest growth and new lands are taken up.

Soils vary greatly in their powers of endurance. We have deep, rich soils and we have thin, poor lands. We have black soils which are nearly always more productive and more lasting than white soils and we have the red soils which are generally more productive than the yellow soils.

Most soils deteriorate through neglect and insufficient and injudicious cultivation. It is a general experience that soils deteriorate under tenant farmers, who have little interest in the welfare of the farm beyond the year of certain occupation and little capital and from analysis about the same amount of mineral plant food in both solutions. If we now grow seedling wheat plants in these solutions, we shall get a much larger growth in the extract from the fresh or fertile soil than in the other. So we have transmitted the properties causing infertility from the soil to the extract. If, now, to the extract from the poor soil, we add fertilizers, we may find that the plants will grow as well as in the extract from the good soil. This would look on the face of it as if infertility were due to a lack of plant food, in spite of the results of the chemical analysis. But if we add certain organic substances which are easily oxidized or reduced and which contain no mineral plant food at all, or if we add solid and insoluble absorbing agents, like carbon black or absorbent cotton, and filter the solution away from them, then the plants will grow equally as well as in the extract from the good soil or as in the extract from the poor soil to which fertilizers have been added. This proves that it is something present in the extract, rather than the lack of something needed by the plants, that retarded growth. Finally, in a soil in which wheat has recently grown we have been able to separate a crystalline organic substance which was not present in the soil before the wheat was planted. This substance is toxic to wheat plants and if present in the extracts or in the soil in certain concentration will kill the plants and in smaller proportions will retard their growth and cause infertility. We have proved in this way, by a large amount of investigative work upon worn-out soils from all parts of the country, that infertility is often due to the presence of toxic organic bodies in the soil, either excreted by the previous crops or perhaps formed by the action of bacteria, molds, or ferments from the plant remains.

NATURE AND PROPERTIES OF TOXIC BODIES.

These toxic bodies are organic. They may be fatty bodies, nitrogenous bodies, or nonnitrogenous. They appear to be quite unstable in the soil, changing rather easily by oxidation into harmless or even into beneficial bodies. They are not equally harmful to all plants. The product from cowpea soil, which has been obtained in pure crystalline form, while toxic to cowpeas is not so harmful to wheat, and with wheat growing in the solution the body appears to be decomposed, and the solution or the soil after the wheat is again suitable for cowpeas. This is believed to be the result of oxidation, and the experiment proves that this may be aided by plants themselves and still more by plants and fertilizers together. Bacteria also aid in this oxidation or reduction of the toxic bodies, especially if only a small quantity be present. Some of the mineral salts of these toxic bodies are quite harmless, and fertilizers may aid by going into combination with these organic bodies.

POSSIBLE MEANS OF AMELIORATION.

Knowing the nature of the trouble, the source in some cases at least, and the properties of the toxic substances, we are prepared intelligently to provide means for the amelioration of the soil conditions. We know that these toxic bodies are more apt to form and accumulate or less likely to change where aeration is deficient, as in an overwet soil; so when such conditions prevail we must provide better aeration by thorough underdrainage. We know that the proper fermentation of organic matters does not proceed well with too much aeration; hence the need for compacting a very loose soil.

Cultivation of itself, and especially if accompanied by a light dressing of decomposed organic manure, tends to hasten oxidation. But deep cultivation must not be too frequent.

In improving a loam soil which is raw and unproductive, put on a light top dressing of well-rotted manure and turn it under about 3 or 4 inches deep. Let this stand four weeks to ferment, then turn it over about 2 inches deeper; then plant a crop—rye or cowpeas if the soil is very poor. With such treatment the soil will gradually darken throughout, although it may take two or three years to bring it up to a fair state of fertility. The change in condition will be evident to the eye. Each type of soil will, however, require somewhat different treatment, and the method of cultivation adapted to one soil will not perhaps be suited to another. Judgment and experience is required in the cultivation of an infertile soil with a view to improving it, even more than in maintaining the fertility of a productive soil.

The improvement of an infertile soil or the changing of a raw subsoil into a true soil involves a fermentation of organic matter to produce other and more stable compounds, just as in the fermentation of tobacco to produce quality in the leaf, the fermentation of malt, the ripening of cheese and of fruits, and the "raising" of bread. Cigar tobacco will not develop aroma by hanging in a barn in contact with air. It must be put into a bulk, built neither too compactly nor too loosely, and the amount of moisture, temperature, and aeration must be carefully regulated, with respect to the peculiar character of the leaf and the purposes for which it is intended, to get the best results. So in the proper fermentation of the organic matter of the soils we must study more the laws and conditions of fermentation, and we must realize that this is greatly aided by enzymes and plant life itself, either by the lower bacterial forms or by the higher forms—the crops and even the weeds and other native vegetation. Cultivation thus appears a great subject for investigation, which, as our methods of soil investigation are becoming more perfect, can probably soon be taken up and worked out.

After cultivation the most important thing is the selection of the proper crop, even of the proper variety of any particular crop and the proper rotation of the selected varieties. This will undoubtedly aid in improving a soil, for reasons which we have seen, and more often still it will prevent soil deterioration. No exact or thoroughly satisfactory system of crop rotation has yet been worked out for any particular soil, and it is time the subject was taken up and studied by thoroughly trained scientific investigators.

After cultivation and rotation we have fertilization as an important and powerful factor, if properly used, in soil improvement, commercial fertilizers, stable manure, and green manures each having an important place in the general scheme. The proper crop rotation and the fertilizer treatment for a soil can probably be best worked out empirically by the paraffin wire-pot method, supplemented by field trials.

We have, then, proper drainage, cultivation, aeration, rotation, and fertilization, all acting to the same end, namely, the maintenance of sanitary conditions in the soil to increase the productive capacity of worn-out lands.

PERMANENCY OF SOIL FERTILITY AS A NATIONAL ASSET.

The soil is the one indestructible, immutable asset that the Nation possesses. It is the one resource that can not be exhausted; that can not be used up. The general conception of the exhaustion of soils is that the crop removes plant food, and that unless we return some considerable portion of plant food to the soil it eventually becomes incapable of longer producing adequate crops. To quote from a recent article in one of the agricultural journals:

> We have warned our readers for the last ten years of what is coming if they continue to grow grain crops and sell them off the farm continuously from year to year. * * * Don't imagine for one minute that your soils are of inexhaustible fertility. No such soils were ever made in the Western Hemisphere, except, perhaps, such as are enriched by overflow every three or four years.

The impression prevails that our crops take out phosphoric acid, potash, and nitrates to such an extent that the soil becomes incapable of longer supplying these plant-food constituents for a satisfactory yield. Several articles have been written recently, calling attention to the calamity which is likely to confront us in a few years because of the exhaustion of one or more of the elements of plant food if the present practices are continued.

Sir William Crookes, president of the British Association for the Advancement of Science, takes a very gloomy view of our ability to continue any longer to obtain from natural sources sufficient nitrates to replenish the diminishing supply of nitrates in our soils. More recently, even, the question of the exhaustion of phosphates from the soils of southern Illinois has been considered, and we are told that the supply is only sufficient for about seventy crops such as are now being harvested. Gloomy indeed are some of the predictions that are being made in regard to the probable failure of the soil to support the increasing population of the earth. In an article on the " Effect of Milk Selling on the Soil," in the Agricultural Gazette, November 7, 1904, Mr. John Wrightson, in reference to a previous article in the same journal, says:

> In the transactions of the Highland Agricultural Society he will find papers upon the serious injury to the highland sheep walks due to the constant drain upon them of phosphates through the continuous sale of lambs. The fact is that both in the highlands of Scotland and in the United States of America the stock lands have been in many cases ruined, or are in process of being ruined, simply by the annual depletion of phosphates. These cases are parallel with the sale of milk, as bone earth (phosphate of lime) is an important constituent of the milk.

In the same publication, November 14, 1904, Primrose McConnell replies to Mr. Wrightson in the following language:

> It is rather strange at this time of day, after all that has been said and written on the subject, to find anyone harking back to the old fallacy that the keeping of milch cows impoverishes the land. In Cheshire dairying has been carried on for seven centuries, yet a small dressing of bones renovated the pastures within our times. In my native county of Ayr dairying has been carried on for two and a half centuries, yet I have never heard of any impoverishment, but the contrary, and I affirm that if any alleged case of impoverishment is inquired into it will be found to be either mythical or due to exceptionally bad management. In my own case, where twenty years ago it took 2½ acres to graze a cow during the summer, those same fields now require 1½ acres to do the same, and on one occasion 1 acre per head was sufficient—their droppings have so enriched the land.

To show why the Bureau of Soils believes the direful predictions of the exhaustion of soils are unfounded, and why we have come to believe that the soil is indestructible and in the main unchangeable, except through our gross neglect, it will be well to discuss some of the supposed cases of soil exhaustion in this country.

SOME SUPPOSED CASES OF SOIL EXHAUSTION.

The Division of Soils, now the Bureau of Soils, was organized about twelve years ago for the study of the soil resources and the soil conditions of the United States. One of the important works undertaken by the bureau was the soil survey, and this has been continued now for about eight years, during which time over 147,000 square miles have been mapped in representative districts throughout the country. It was from the first realized that in surveying and mapping the soils it would become necessary to study for our farmers some of the great soil problems encountered in the areas, especially such as concerned the management of the soil and the production of larger crops on certain soils.

There has been an impression for years that our virgin prairie soils are becoming exhausted. There is an impression in other sections of the country that the continued use of fertilizers has injured the land. We have seen in the last few years rural sections of the country almost depopulated and a disquieting increase of abandoned farms. Involved in these beliefs and changes appeared to be problems of great National importance.

Some years ago, through an arrangement with the Virginia Board of Agriculture, the Bureau of Soils made quite an extensive investigation of the soils of Virginia. Attention was called at that time to the poor soil condition in certain sections of the State, particularly in middle Virginia, where it appeared that the soils once fertile had worn out; that they had become exhausted. There was at least truth in the claim that agriculture had declined. Later, when we were preparing to take up some important problems in soil fertility, middle Virginia suggested itself as a locality where the Bureau might do some effective work on soils which by general consent had reached about the lowest possible stage of crop production through an actual exhaustion of plant food. In a report covering this area it was subsequently shown that conditions have markedly improved; that the crop yields on most of the soils are now fairly satisfactory, and that good methods of cultivation and attention to crop rotation, together with the introduction of more live stock and the utilization of the manure produced, will unquestionably in a short time bring this area up to a really satisfactory condition. There appears, therefore, to be no problem presented here of an actual exhaustion of the mineral plant food of the soil, as a mere change of cultural methods has been sufficient to increase the general productivity of the soil of the area in from eight to ten years.

In 1901 a soil survey was made of Prince George County, Md., and the general impression at that time was that these soils had become so far exhausted that the yields were unsatisfactory. This was another area considered as a suitable locality for investigating the actual exhaustion of plant food from a soil. The opinion of the Bureau, however, has been that these soils were not exhausted of their plant food, but were still capable of producing satisfactory crops with improved methods and with proper crop rotations, and this proved to be the case, for it was found that within a period of less than five years the methods had already been improved, and that the crop yields were much better than formerly. There is thus every reason to believe that with better methods of cultivation, more attention to crop rotation, and the introduction of live stock the problem of the fertility of these soils will be satisfactorily worked out. This would indicate that the unproductiveness of lands in the condition presented in 1901, when the survey was made, is not due to an actual exhaustion of plant food, but to some other cause or causes which deserve consideration.

For three years, under orders from the Secretary, the Bureau of Soils had one of its men detailed as an instructor in soils at Cornell University. We had heard a good deal of the abandoned farms in portions of Tompkins County, N. Y., in which Ithaca is located. Upon looking into this matter we could find no evidence that the crop yields were less now than they were years ago. There were abandoned farms, but this was due to other conditions than the exhaustion of the soil.

Another problem presented itself in the abandoned farms of New England. So a soil survey party was sent into Merrimack County, N. H., where many farms were reported as being abandoned, the country generally having gone backward as an agricultural community, and where the question of reforesting was being agitated. These men reported the soils in good condition, the yields good, and no evidence could be found in that particular region of any general deterioration so far as the soil is concerned.

About six years ago the Industrial Commission held hearings in regard to the causes leading up to the abandonment of farms. This subject was treated rather exhaustively, and a report (No. 70, of the Department of Agriculture) was published giving the testimony. As this report is available, the principal contributing causes only will be given here. These are the development of new areas and new industries; the introduction of farm machinery incapable of being used in certain districts; attempts to grow crops unsuited to particular soils; unfavorable climatic conditions; scarcity of water in desert country; alkali and seepage water; flooding and inundations by storms and tides; labor and expense of maintaining proper physical conditions; transportation conditions; social conditions; deterioration of farms through improper methods of cultivation; injudicious crop rotation.

It appears, therefore, that this great problem which has presented itself in different parts of our country—the abandonment of farms—is due not to the exhaustion of the soil, but to other conditions—mainly social and labor conditions.

In 1906 the bureau had a soil-survey party in Blue Earth County, Minn., in one of the wheat areas of that State, and the men reported that it was generally believed that, owing to the exhaustion of the soils, the yields of wheat had decreased from 30 to 40 bushels per acre fifteen years ago to 12 bushels per acre now. The belief that the prairie soils of the West have deteriorated is very widespread, not only in this country, but also abroad. There is constant reference to this fact in the agricultural literature and in the scientific journals of this country and of Europe. The Bureau had the records examined to see if undoubted statistical evidence that the soils had deteriorated could be found, using the crop as a measure of the soil fertility. It was found that the available statistics—running back to the year 1874 and up to 1898, a period of twenty-five years—for four typical wheat counties in Minnesota, three of them in the Red River Valley, and also for the State at large, showed no evidence of a decline in yield, but on the contrary only that fluctuation due to seasonal differences. The yearly records fail to show the large yields in the past that we are accustomed to attribute to those soils. The yields for Blue Earth County itself, as well as for the three typical wheat counties of the Red River Valley and for the State at large, are shown in the following table:

Yield per acre of wheat in the State and several counties of Minnesota.

Year.	Kitson County.	Polk County.	Clay County.	Blue Earth County.	Average for State.
	Bushels.	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
1874	....	8.87	....	12.83	14.23
1875	....	17.25	14.69	13.51	17.05
1876	....	11.75	5.49	18.87	9.61
1877	....	25.19	16.85	16.35	16.79
1878	....	....	....	....	12.50
1879	22.92	16.88	16.13	8.14	11.90
1880	19.10	16.40	16.87	13.43	13.30
1881	18.79	17.55	17.18	6.74	11.42
1882	21.78	15.11	16.03	14.00	13.81
1883	15.18	14.22	15.09	13.53	14.37
1884	21.21	16.18	13.87	17.31	16.35
1885	14.80	13.40	9.20	16.90	13.55
1886	13.80	15.10	22.10	17.20	15.80
1887	25.70	18.30	12.40	18.40	....
1888	....	10.00	12.00	....	....
1889	....	....	....	26.90	15.30
1890	....	13.50	13.70	13.30	13.00
1891	....	....	....	17.40	18.10
1892	3.20	....	10.80	12.30	11.80
1893	15.00	....	9.40	12.00	10.70
1894	19.30	11.70	10.50	12.90	13.00
1895	27.00	20.10	19.90	19.40	18.53
1896	7.70	12.00	13.20	....	12.80
1897	14.33	12.00	11.02	17.20	9.11
1898	15.43	12.00	11.24	....	....

So far as our researches have gone, and so far as we can rely upon statistics of this kind—and we have not gone beyond the simple returns that have been published—it seems to us that the general impression of the deterioration of soils, the general idea that has been held about soil exhaustion due to an actual exhaustion of available plant food, is erroneous.[a] It will be shown later that the soil can be abused; that there is no question that the yield will deteriorate with improper methods of cultivation and with improper systems of crop rotation, but in a large area, such as a county or a State, there are other factors of changing owners and different usages which may influence the final results and make the actual statistics more uniform than we would expect from the records of a few individual farms. When the land becomes unproductive it is thrown out of cultivation, and when it is taken up again for cultivation it is found to be improved.

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[a] This subject is being treated much more exhaustively for the National Conservation Commission, and this conclusion is being confirmed and strengthened.

It is hardly necessary for me to refer to the fact that we have erroneous impressions in regard to events that have taken place in the past. In a recent number of the Monthly Weather Review[a] there is a very able article entitled "Present Day Climates in their Time Relation," by Prof. Frank Morris Ball, of the Department of Geology, University of Minnesota, in which he says:

> It is often asserted by people who have lived in a locality for many years that the climate of their region has undergone marked changes during their residence, the most common statements being that cold weather came earlier in the fall; that greater snowfall was experienced; that the thermometer registered more continuously low temperature in years past than at present, and that the rainfall is increasing or decreasing in amount. In the light of modern science such statements are open to serious question. The human organism is at best an inaccurate register of temperature, and memory is more liable to be impressed with some single manifestation of weather than with the average of weather conditions which go to make up climate. A vivid impression of a day on which the thermometer registered 40° below zero is quite likely to remain in the mind for a long time, but the week of moderately cold weather which followed the cold snap and which, when averaged with the lowest temperature noted, made only average winter weather, is quite likely to be unnoticed, or, if noted at all, soon forgotten. * * * If we stop a moment to reflect that the factors of climate are under the direct control of natural laws, no surprise will be occasioned because of the permanency of climatic averages. That seemingly most willful and lawless of all elements, the wind, is no less under the direct control of law, and responds to it with no less unhesitating obedience than does the earth to the law of gravity in its yearly swing around the sun.

The last paragraph of this article is particularly important:

> No better proof of the relative nature of all human knowledge and the temporary character of all human conclusions can be found than in the above paragraph. The most elementary knowledge of geology and related earth sciences is sufficient to prove that climates have changed many times in the geologic ages through which the earth has passed. All theories accounting for such changes lead irresistibly to the conclusion that climates to-day must be changing, although not in any measurable amount.

There is no question that our soils are changing, but to the finite extent of human knowledge it is very much to be doubted whether there have been any measurable fundamental chemical changes in the mineral soil material of the lands that we actually cultivate, save such as are brought about by erosion by wind or water.

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[a] Volume 34, May, 1906.

THE TRUE NATURE OF THE SOIL.

It has been taught that the soil results from the disintegration and decomposition of the minerals contained in the original rocks, and strong emphasis has been placed upon the decomposition of these minerals in the formation of soils. On the contrary, as has been shown in the first part of this bulletin, the soil is essentially an aggregation of mineral particles coming from the disintegration of rocks, and to some extent from the decomposition of the original minerals themselves, but one will find in all soils a large number of minerals which can be recognized as having been present in the original rocks. The older agricultural soils of Europe and of Asia contain the same common rock-forming minerals as the newer soils of the United States, and the chemical composition as determined by analysis of the mineral portion shows no essential differences. The fact that the lands of Europe have been occupied for one thousand years or more has not made a noticeable reduction of the plant food element as compared with the new soil of this country.

RELATION OF THE SOIL TO PLANT NUTRITION.

The old idea of soil fertility was that plants could not avail themselves of the potash or phosphoric acid until the rock particles, the minerals, were decomposed and their constituents made available to the plants. It is, however, merely a question of the solubility of the mineral particles themselves. One can take the minerals obtained from the soil, or minerals from museum collections, and by grinding them up and adding water and a little nitrate can get a soil solution which is comparable with the soil solutions of our fields, and can grow as good plants in the extract from the cabinet specimens so prepared as in the extract of the soils itself. The plants can avail themselves of the potash, phosphoric acid, and lime which are dissolved directly from these mineral particles. Not only so, but if we take these minerals and wash them by repeated leachings, we will continuously get quantities of potash, phosphoric acid, and lime dissolved in the water. After leaching repeatedly and frequently during the day, if we leave the particles in contact with a fresh portion of water overnight, in the morning the concentration of the solution will be about the same as it was the morning before, so immediate and rapid is the recovery and so adequate and ready is the supply of these mineral nutrients.

We have in our soil moisture a solution which carries sufficient mineral nutrients for the support of the plants. It is capable of maintaining its concentration by re-solution from the minerals to supply any portion of these plant food constituents that may be withdrawn. Under ordinary conditions of drainage and of rainfall the concentration can not get too large, nor can it for any considerable period get too small for the need of plants. In other words, we have in the soil a most efficient system for supplying the nutrient food for plants.

This, therefore, is the nature of the soil and of the soil moisture. It is a great nutrient medium for the support of plants, spread out over the surface of the earth, and as all soils, with but possibly few and unimportant exceptions, are made up of a great number of minerals, it follows that the concentration and the composition of the soil moisture in our different types of soil varies but little. One might expect to find that in such extreme cases as the heavy clay soils of the limestone Valley of Virginia, the black prairie soil of Texas, or the Norfolk sand of the Coastal Plains there would be marked differences in the composition of the soil moisture, but our investigations show that the moisture has about the same composition in each of these widely different types of soils, or at least such differences as do occur are not sufficient to explain the observed differences of crop adaption and yield.

HISTORICAL EVIDENCE THAT SOILS DO NOT WEAR OUT.

Attention will now be called to some very striking historical and statistical data that seem to prove that soils do not wear out, and inferentially that they will not wear out in finite time.

It has long been a mystery how soils have continued to support crops for a thousand years and more, and the mystery becomes deeper when we realize that in the oldest cultivated countries there is no sensible diminution of plant food. We have the general history of China that goes back probably for four thousand years. There are many sections of that country that have undoubtedly supported a population for at least as long a time as that. It is said that they are very careful to return the excrement both from man and animals to the soil, but there must be some loss, some waste, and in four thousand years this would amount to considerable. But there are no signs of deterioration of these soils. There is no evidence that these soils are going back, and the fact that they have been careful in their cultivation only goes to show what we could do with our soils if we exercised reasonable care.

Coming down to more recent times, of which we have actual statistical records, it can be shown that so far as statistics can be relied on, without going back of the returns, without finding out how these statistics were taken, and just what value they have, the soils of the world, or at least of the European countries, are not wearing out, but that they are actually improving.

Prof. Wilhelm Kellerman[a] in an article on the "Increase of Crop Production in Germany," published in one of the German scientific journals, has been fortunate enough to get the actual yields of some of the old German estates which have been handed down in the same families for a long period of years. The figures from three of these estates have been taken as illustrations that the yield in these older countries is not decreasing, that the lands are not becoming exhausted, but that, on the contrary, there has been a material increase in the production per acre. A record from one estate goes back to 1552. The period from 1552 to 1557, apparently the average for those years, gives a yield of wheat of 12.5 bushels per acre. In 1670 there is a record of 14.6 bushels, in 1822 of 18.7 bushels, in 1825 of 18.1 bushels, in 1840 of 25.6 bushels, in 1850 of 28.7 bushels, in 1880 of 35.3 bushels, in 1897 of 45.1 bushels, an increase in those three hundred years from 12.5 bushels in 1552 to 45.1 bushels in 1897, the record showing a regular increase, with a few fluctuations which are probably due to seasonal conditions.

Yield of cereals in Schmatzfeld, Germany.

Year.	Wheat.	Rye.	Barley.	Oats.	Year.	Wheat.	Rye.	Barley.	Oats.
	Bushels.	*Bushels.*	*Bushels.*	*Bushels.*		*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
1552–1557	12.5	13.2	14.2	14.8	1840	25.6	30.0	31.6	45.5
1660	....	12.8	8.3	12.3	1850	28.7	33.1	39.3	50.1
1670	14.6	17.2	16.1	17.4	1860	35.3	39.3	32.9	62.9
1810	....	....	....	....	1870	27.6	20.4	45.8	46.6
1820	....	....	....	....	1886	37.9	28.9	43.2	66.6
1822	18.7	24.3	33.7	26.2	1887–1896	40.0	29.6	47.6	59.7
1825	18.1	20.0	28.1	32.5	1897–1904	46.1	34.0	50.4	69.1
1830	18.7	21.2	35.6	46.2					

From another estate records apparently even more complete are given in five and ten year periods from 1756 to 1904. The average yield of wheat in the first period reported (1756–1765) is 26 bushels; in the next period (1766–1775) it is 13 bushels; and from there on a gradual increase took place up to 1900–1904, when it was 36 bushels. Rye increased similarly by regular steps from 15.91 bushels to 32.52 bushels; barley from 14.25 bushels to 43.23 bushels; oats from 23.03 bushels to 57.80 bushels. The details are given in the accompanying table.

Yields of cereals on Rittergut Trebsen, near Leipzig.

Year.	Wheat.	Rye.	Barley.	Oats.	Year.	Wheat.	Rye.	Barley.	Oats.
	Bushels.	*Bushels.*	*Bushels.*	*Bushels.*		*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
1756–1765	26.41	15.91	14.25	23.03	1825–1834	21.04	21.63	30.19	31.88
1766–1776	13.25	12.33	21.71	23.48	1835–1844	33.40	27.92	36.66	46.54
1776–1785	16.63	14.47	20.44	23.45	1845–1849	25.51	28.75	....	56.25
1786–1795	13.98	13.67	16.77	19.16	1883–1892	27.03	23.06	30.95	44.64
1796–1800	13.89	15.86	15.16	17.90	1893–1894	29.85	28.86	30.95	54.74
1814–1816	15.28	15.68	25.41	25.72	1896–1899	35.85	30.45	35.39	51.15
1820–1822	16.90	19.14	18.28	26.36	1900–1904	36.14	32.52	43.23	57.80

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[a] Landw. Jahrb., 35, p. 289 (1906).

From a third estate records are available in ten-year averages from 1800 to 1894, and wheat has shown a continual increase from 21.15 to 35.70 bushels; rye from 14.64 to 29.52 bushels; barley from 19.8 to 41.06 bushels; oats from 17.22 to 43.96 bushels. The details are given in the accompanying table.

Yields of cereals on a German estate.

Year.	Wheat.	Rye.	Barley.	Oats.	Year.	Wheat.	Rye.	Barley.	Oats.
	Bushels.	*Bushels.*	*Bushels.*	*Bushels.*		*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
1800-1810.....	21.15	14.64	19.80	17.22	1860-1865.....	29.77	30.48	37.85	44.52
1810-1820.....	20.02	11.76	20.92	13.44	1865-1870.....	27.45	26.48	36.17	55.72
1820-1830.....	23.25	17.76	21.29	14.81	1870-1875.....	29.92	28.32	35.71	51.38
1830-1840.....	18.82	15.04	16.37	13.86	1875-1880....	28.12	24.32	29.38	39.48
1840-1850.....	23.10	19.84	20.83	27.58	1880-1885.....	25.57	25.12	36.45	45.08
1850-1855.....	26.40	23.12	32.75	33.46	1885-1894.....	35.70	29.52	41.06	43.96
1855-1860.....	25.27	24.16	27.71	34.44					

Professor Kellerman makes this very interesting assertion in his article:

> If we now make a brief survey of the results obtained in the foregoing, we must affirm that the development of the yields of cultivated soil since the beginning of the past century presents a very pleasing picture. Not only that agriculture by absolute addition to the acreage of 30 to 35 per cent and decrease in fallow from 33 to 4½ per cent has tried to meet the growing need of the nation for food, but above all that it has shown how to gain from the soil gradually two and one-half times as much per unit of surface as formerly.

There is available in the report of the French minister of agriculture the yield of cereals for France from 1815 to 1876, and the figures show that during this period of fifty years wheat, rye, barley, and oats have all increased.

Yield of cereals in France.

Year.	Wheat.	Rye.	Barley.	Oats.	Year.	Wheat.	Rye.	Barley.	Oats.
	Bushels.	*Bushels.*	*Bushels.*	*Bushels.*		*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
1815-1824.....	11.86	10.10	14.45	17.12	1855-1864....	15.90	14.11	19.90	24.98
1825-1834.....	13.44	12.34	14.64	17.78	1865-1874....	15.81	14.65	19.75	24.49
1835-1844.....	14.30	13.01	15.92	20.10	1875-1876....	16.60	15.71	19.00	23.61

Wheat has increased from 11.86 to 16.60 bushels; rye from 10.1 to 15.7 bushels; barley 14.4 to 19 bushels; oats from 17.12 to 23.61 bushels.

Records are also available for Germany from 1881 to 1900, and during that time the yield of wheat has increased from 21.75 to 26.55 bushels; rye from 18.56 to 23.04 bushels; barley from 29.07 to 32.49 bushels; oats from 36.96 to 45.08 bushels. This is for the entire area of the German Empire. The details are given in the table on the following page.

Yield of cereals in Germany.

Year.	Wheat.	Rye.	Barley.	Oats.
	Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
1881-1885	21.75	18.56	29.07	36.96
1886-1890	22.65	19.04	29.07	40.32
1891-1895	24.30	21.28	31.54	40.88
1896-1900	26.55	23.04	32.49	45.08

Statistics for the whole of Europe from 1876 to 1904 show a gradual increase in yield per acre of all cereal crops. Wheat has increased from 12.90 to 15 bushels; rye from 11.84 to 14.08 bushels; barley from 17.86 to 18.62 bushels; oats from 24.08 to 27.16 bushels. The details are given in the accompanying table.

Yield of cereals in Europe.

Year.	Wheat.	Rye.	Barley.	Oats.	Year.	Wheat.	Rye.	Barley.	Oats.
	Bushels.	*Bushels.*	*Bushels.*	*Bushels.*		*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
1876-1880	12.90	11.81	17.88	24.08	1891-1895	14.10	13.28	19.76	26.32
1881-1885	13.65	12.16	18.43	24.36	1896-1900	13.95	14.08	18.62	27.16
1886-1890	13.50	12.48	18.62	25.20	1901-1904	15.00	....	....	....

The records of Denmark, Holland, Belgium, Norway, Austria, and other European countries for which data are available show continued increase in the yield per acre of cereal crops, as in the cases cited above.

From this historical evidence it appears that on these old soils of the old countries, which have been under cultivation for a thousand years, the yields within the last century have actually increased, as shown not only by general statistics gathered by the States, but by the statistics of individual farms which have been continually under the management and in the possession of the same families. This shows that, so far from wearing out, these soils have been steadily increasing in productivity within the period of which we have statistical records. This increase is due to better methods of cultivation, more systematic rotation of crops, more care in the selection of seed, increase of live stock, and in later years to the introduction of commercial fertilizers—guano from Peru, nitrate from Chile, phosphate from the United States, potash from Germany; but how much is due to each of these factors can not be determined by any available records.

FERTILITY OF SOILS CAN BE TEMPORARILY IMPAIRED.

While in the foregoing it has been shown that soils do not wear out in the sense that we have been accustomed to use this term and that there is no general deterioration of lands, the individual can abuse his soil as he can abuse his own physical powers, but in the long run, even in the finite time with which we are concerned, it does not affect the great problem of the general fertility of the soil. It is but a detail making up the general average of national soil conditions.

The fertility of the farm can be temporarily impaired by improper or careless cultivation, as in the case of cotton soils of the South, where erosion is so rapid that we can hardly maintain from year to year the soils that we last year cultivated. And what becomes of the soil that is eroded? It forms the fertile rice lands of the deltas of the rivers. These are the soils from the poor washed lands of the up-country changed as to their organic matter content, which they have acquired in their gradual progress down the streams, and changed as a result of this organic content in their physical properties, but unchanged with respect to the kind of minerals they contain. They are not and never have been exhausted of plant food. With this change of state they are wonderfully productive.

The fertility of the soils can also be temporarily impaired by improper rotation of crops as has already been shown.

A recent bulletin (No. 96) of the South Dakota Experiment Station reports a very interesting experiment bearing upon this point, not only as regards the possibility of impairment but the ease with which the crop-producing power of the soil can be temporarily impaired.

> The character of the soil and the lay of the land is somewhat poorer than the average in Hyde County. 1903 was a good year for nearly all crops. 1904 was favorable to the maturity of early crops and small grains, but the late drought destroyed most all of the later crops. * * * In 1903 three pieces of land, each 8 rods wide, lying side by side and separated only by roads 1 rod wide, were cropped as follows: One was in wheat, the second was in corn, and the third was summer fallowed. Previously to 1903 all had about the same treatment.

	After wheat.	After corn.	After fallow.
Wheat	2.7	17.8	9.8
Emmer	3	36.9	32.2
Barley	0	23.8	17.5
Oats	1.4	48.1	54.4

> * * * The season of 1904 at Highmore was very dry, the rainfall for the five growing months being 8.55 inches.
>
> * * * As a result of the dry weather, everything was a total failure on the land that had grown a crop of small grain the year before.
>
> * * * On the land that had been in corn the year before, separated from the latter plats only by a road a rod wide, sown with the same drill, the same seed, and at the same time, we harvested a reasonably good crop of all kinds of grain.
>
> * * * On the summer-fallowed land lying next to the corn ground and with all conditions the same except the preparation of the land, the crop was

fairly good, but with the exception of the two varieties of oats was not as good as on the corn ground.

* * * All our experience goes to prove that as good a crop of grain can be grown following a well-tended crop of corn as can be grown after the best summer fallow. In fact, we have some very strong evidence now to prove that the fertility and crop-producing powers of the soil are maintained longer by a system of alternate cropping to corn than they are by a system of summer fallowing.

* * * This instance of small grain being a total failure when grown after small grain in a dry year, while at the same time a good crop was produced after corn is not an isolated case, but it is the general rule. In fact, it is becoming so well known that in some sections of both this and other States with similar climatic conditions farmers make a practice of planting half their land to corn or some other cultivated crop every year, and never think of sowing small grain after small grain. It is the introduction of such practices as this, with their attendant good results, together with the introduction of varieties of grain adapted to the conditions of soil and climate that lends color to the more or less general belief that the climate is undergoing a permanent change.

They find, therefore, that grain does materially injure the soil for grain again, that corn appears to improve it, even over summer fallow, and yet during the fallow no plant food is removed, while with the crop of corn certainly a considerable amount of plant food is removed, notwithstanding which the soil is left in better condition for the following crop. Whether this was due to moisture conditions, the presence of toxic substances, or other causes, the results bring out very strikingly the effects of different methods in improving the crop-producing power of the soil.

To these very striking illustrations could be added any amount of evidence of the deterioration of fields in almost any community. Lands normally producing from 40 to 60 bushels of corn per acre if turned over to tenant farmers are liable to become very unproductive in a short time. They take on the appearance that we attribute to worn-out and exhausted soils, but surely their present condition is not due to the loss of plant food, since by the gradual " exhaustion " by poor farming these lands have constantly produced less than the better farmed fields. In such cases it is well known that these lands could easily be brought up to produce fair crops by better methods of cultivation.

The great point to be made here is that our judgment is apt to be influenced by these individual cases of the temporary impairment of the productive power of the soil and that statistics fail to show that there is any widespread exhaustion or deterioration of the soil.

As we see it now, the main cause of infertile soils or the deterioration of soils is the improper sanitary conditions originally present in the soil or arising from our injudicious culture and rotation of crops. It is, of course, exceedingly difficult to work out the principles which govern the proper rotation for any particular soil.

The important thing is that we now understand the nature of the soil; how it supplies the nutrient constituents for the crops and how it maintains this supply; how crops may affect each other when grown in succession on the soil; how cultivation affects the conditions resulting from the crop, and, lastly, we are beginning to understand how fertilizers come into this scheme and themselves act on or change toxic conditions in the soil, rendering the soil again sweet and healthy for the growing crop.

It has been shown that our impressions of the deterioration of the wheat soils of the Northwest are apparently incorrect. These impressions have probably been derived from exceptionally high yields on certain farms and from recollections of individuals, frequently recorded in newspaper articles. As a matter of fact, the soils as a whole are actually producing more now with the introduction of better methods than they formerly did. For analogy reference has been made to the impressions which are prevalent in regard to a change in the climate.

It has been shown that on abandoned farms in certain areas in the New England States and in New York the actual yield per acre is as great now as it was formerly, and that the cause of the abandonment of the farms must be sought in other lines than the exhaustion of plant food from the soils.

It has been shown that in southern Maryland and in middle Virginia the cause of the recent depression in agriculture and of the low yield of crops is due to methods which have prevailed rather than to any exhaustion of the soil, and that with improved methods these areas are coming up and will again be made to produce satisfactory crops. The soils are not wearing out in the sense that they are unable longer to provide mineral nutrients, but the yields are low because through the prevailing methods the soils have not been maintained in proper condition. In these latter instances the yields have actually declined, but not from the cause which has been generally ascribed.

It has been shown that from the modern conception of the nature and purpose of the soil it is evident that it can not wear out, that so far as the mineral food is concerned it will continue automatically to supply adequate quantities of the mineral plant foods for crops, but it has also been shown that the soil can be abused and its fertility temporarily impaired by improper methods of handling.

Lastly, it has been shown from the statistics of European countries that the soils of the world are not wearing out, but that, on the contrary, after a thousand years of cultivation, with the introduction of better methods, with the necessity of raising larger crops, these soils are responding with an increased yield even over what they produced at the beginning of the last century.

As a national asset the soil is safe as a means of feeding mankind for untold ages to come. So far as our investigations show, the soil will not be exhausted of any one or all of its mineral plant food constituents. If the coal and iron give out, as it is predicted they will before long, the soil can be depended upon to furnish food, light, heat, and habitation not only for the present population but for an enormously larger population than the world has at present.

Personally, I take a most hopeful view of the situation as respects the soil resources of our country and of the world at large. I can not bring myself to believe that the discouraging reports that have been issued from time to time as to the threatened deterioration of our soils, as to the exhaustion of any particular element of fertility, will ever be realized. While I know that soils do change in the infinite order of time, I have no thought that they do change materially, structurally, profoundly, in the finite range of human experience or of human knowledge. It is dependent upon us to study the soil to understand the changes brought about by cultivation and by cropping, to win from the soil not only our present yields, but increasing yields for the larger population that we can reasonably expect.

It must not be assumed that even if these commonly accepted impressions regarding the deterioration of soils through loss of plant food are wrong, that there is no field for soil investigation. The question is just now assuming the importance of a science. We are just beginning to realize the nature of the soil, its functions, and its relations to crops. There are certain great problems that will have to be worked out under government auspices. These questions are too far-reaching, too profound, too universal, for any one person or any local institution to solve. The laws governing the soil and its relation to crops, including the rotation of crops, have to be better understood. Upon what principles are they based? What does the plant do to the soil? What do bacteria do to the products of the plant? How can these agencies be aided or controlled for the good of mankind? Why does not the soil purify itself and keep itself in condition to destroy the waste products of the plant? It ought to do so. It is intended that it should and in the best soils it does.

We will have to understand better than we do now the necessary physical treatment of soils through methods of cultivation—what cultivation does, how it improves the texture or the sanitary conditions of the soil. We know that the soil needs stirring; it needs change. Just how does this operate to improve the condition of the soil for the coming crop? The way fertilizers act, and when and under what conditions they are necessary, and how most effective, are questions which must be better understood than they are at present.

PART II. CLASSIFICATION AND DISTRIBUTION OF THE SOILS OF THE UNITED STATES.

INTRODUCTION.

The soil is the greatest natural resource of the Nation. With the exhaustion of coal and iron it will supply, if rightly used, not only food and clothing as at present, but also fuel, light, power, and structural materials now supplied to a greater or less extent by these minerals. It produces now over $7,000,000,000 in products annually, forming the basis of our industrial wealth and a large proportion of our foreign exports, yet we are but now taking up the last of our public lands available for cultivation and the country is still so sparsely settled that only about a quarter of the land nominally in farms is actually under cultivation.

From these lands we are getting only a third or a half the yield per acre obtained on the older soils of Europe, and within the past fifty years we have seen in many individual farms the productivity of our new soils decline more than in equal proportion to the increase in productivity of European countries. The population of the country is rapidly increasing and the time has surely come when we must face the situation and when we should take an account of stock and deliberate as to what should be done to increase the returns from the land and yet leave the soil in better condition for succeeding generations. The soil is the one natural resource which, if properly used, not only clothes and feeds us, but improves with age and careful treatment for the continued use of posterity. What these soil resources are the Bureau of Soils is determining through the soil survey. How they should be utilized the department, through its several bureaus and the experiment stations, is learning. But under all, as a basis of all intelligent development, is the knowledge of and classification of the soils.

Few realize the frequent changes of location made by the American farmer and farm laborer. It is not with us as it is in most of the European countries, where families live for generations on the same land until they get from long experience and by force of circumstances and necessity an intimate knowledge of its peculiarities and of the best ways to handle it, although they may pretend to little knowledge of other soils of different texture or other peculiarities. One method of cropping or of soil management can not succeed equally on all our soils, nor can any text-book show all the methods or all the agencies for the improvement of our different soils, but enough is now known about the cause of fertility and infertility for the public to understand that an impoverished or run-down soil is due to extreme poverty of the owner or tenant, to neglect or to actual abuse, as we realize now that these factors form the principal causes of the occurrence and spread of many contagious, infectious, or epidemic diseases.

The Bureau of Soils on January 1, 1908, completed the detailed soil mapping, on the scale of 1 inch to the mile, of areas amounting to 146,606 square miles, or 93,828,114 acres, in continental United States. This work has been widely distributed in 300 areas, usually of county units, in all of the States and Territories except Maine and Nevada. The areas have been selected with some reference to the density of population, and with particular regard to the different agricultural districts and agricultural interests of the country. Comparing this area with the area of certain foreign countries, it will be seen that it is larger than Great Britain (including England, Scotland, Ireland, and Wales), three-fourths the size of France, larger than Italy, and about the size of Japan, but much less thickly populated, as appears from the following table:

Area and population of the United States and of certain foreign countries.

Country.	Area.	Population.	Population per square mile.
	Sq. miles.		
German Empire	208,780	60,641,278	290
France	207,054	38,961,945	188
Spain	194,783	18,618,086	96
Japan	147,655	46,732,138	316
United States (surveyed)	146,606	[a] 6,000,000	41
Great Britain and Ireland	121,391	41,976,827	346
Equador	116,000	1,205,600	10
Italy	110,550	32,475,253	294
Paraguay	98,000	631,347	6
Portugal	35,490	5,423,132	153
Greece	25,014	2,433,806	97
Switzerland	15,976	3,463,609	217
Denmark	15,592	2,605,268	167
Netherlands	12,648	5,591,701	442
Belgium	11,373	6,693,548	589

[a] Estimated.

The amount of work done in each State and the actual cost of the field work, including salaries and field expenses of the men, are given in the accompanying table.

Soil surveys to January 1, 1908.

State or Territory.	Area.	Total cost.
	Sq. mi.	
Alabama	9,746	$26,828
Arizona	859	4,602
Arkansas	2,678	7,512
California	7,552	36,899
Colorado	2,428	8,307
Connecticut	506	936
Delaware	314	498
Florida	2,955	9,876
Georgia	2,423	5,884
Idaho	1,281	2,124
Illinois	5,951	8,634
Indiana	3,544	7,365
Iowa	2,271	3,055
Kansas	3,180	6,784
Kentucky	2,079	3,982
Louisiana	5,775	16,487
Maine		
Maryland	3,605	6,450
Massachusetts	809	1,511
Michigan	3,789	8,307
Minnesota	2,144	5,155
Mississippi	5,840	16,810
Missouri	5,045	7,993
Montana	482	1,900
Nebraska	3,115	5,980
Nevada		
New Hampshire	923	$2,126
New Jersey	1,279	2,477
New Mexico	128	1,200
New York	5,597	14,176
North Carolina	7,727	17,243
North Dakota	4,552	11,208
Ohio	4,144	7,567
Oklahoma	1,163	3,213
Oregon	442	1,855
Pennsylvania	3,744	10,364
Rhode Island	1,084	1,654
South Carolina	6,348	15,010
South Dakota	674	985
Tennessee	4,740	9,204
Texas	12,428	33,822
Utah	1,501	6,608
Vermont	227	528
Virginia	5,916	13,674
Washington	1,651	4,976
West Virginia	1,615	4,268
Wisconsin	2,593	5,479
Wyoming	309	1,070
Total	146,606	371,586

This wide distribution of the work, besides benefiting the people in a somewhat equitable way in each of the States, has enabled the Bureau to acquire in the shortest possible time and with the least expenditure of funds a knowledge of the soils of the entire country that could not have been obtained in any other manner. With the information now available it has been possible to construct a general map of the United States, showing the great soil provinces, although not sufficient work has been done to construct a detailed soil map of any one of these provinces. The following table gives the name and area of the soil provinces and the proportion of each that has been covered by the soil survey. It is not unlikely that as the work progresses and as our knowledge of the soils increases it will seem advisable to divide some of these provinces into two or more parts.

Soil provinces of the United States.

Province.	Estimated area.	Area surveyed.	
	Acres.	*Acres.*	*Per cent.*
Atlantic and Gulf coastal plains	233,000,000	25,613,666	10
River flood plains	64,000,000	8,061,247	13
Piedmont Plateau	48,000,000	7,271,798	15
Appalachian Mountains and plateaus	72,000,000	6,367,009	9
Limestone valleys and uplands	68,000,000	6,052,926	9
Glacial and loessial	455,000,000	22,417,832	5
Glacial lake and river terraces	41,000,000	5,091,882	12
Residual soils of western prairie	107,000,000	1,825,850	2
Great Basin	109,000,000	1,005,600	1
Northwestern intermountain region	76,000,000	1,455,428	2
Rocky Mountain valleys and plains	365,000,000	2,939,840	1
Arid Southwest	58,000,000	1,131,155	2
Pacific coast	21,000,000	4,593,881	22
Western mountain regions	211,000,000		
Total	1,928,000,000	93,828,114	

It is estimated that the areas which have been surveyed contain a rural population[a] of about 6,000,000 people, or about one-sixth of the rural population of continental United States. It is estimated that with the Congressional distribution and the requests which have come to the Department upward of 1,500,000 copies of the soil maps and accompanying reports have been distributed, not only to people within the areas surveyed, but to a large number of people seeking information regarding the soil resources of these areas.

It is proposed now to give a succinct statement of the knowledge that has been acquired of the soils and the soil resources of the United States. No attempt will be made to give a detailed description of the 715 soil types so far encountered and only a very brief description of the 86 soil series which have been established, as this information is given in detail in the separate reports on the different areas and in a more technical way in the Soil Survey Field Book, which can be consulted in most of the public libraries or can be obtained directly from the Department. It is intended briefly to set forth the agricultural value of the several types of soil, or the way in which they are at present being used, mentioning for this purpose, however, only the principal crops or agricultural interests and not going into a detailed statement of all the crops which are grown or into methods of cultivation or soil management. Such a detailed treatment of the soils of the United States would far exceed the limits of this publication and can well be deferred until the soils of the several provinces are written up in detail.

BRIEF DESCRIPTION OF THE SOIL SERIES.

The following very brief description of the soil series which have been established in the United States, arranged under the soil provinces in which they occur, will be found useful as a key to the more detailed descriptions of the soil types which follow:

ATLANTIC AND GULF COASTAL PLAINS.

Bastrop series.—Brown soils with reddish-brown to red subsoils occurring as nonoverflow terraces. Cotton, corn, sorghum, alfalfa, melons, and potatoes are successfully produced.

Crockett series.—Dark-gray prairie soils underlain by mottled red subsoils. Derived from slightly calcareous material, the soils of this series are productive. Cotton and the general farm crops are the leading products. The gravelly soil is early and adapted to early truck.

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[a] Cities of more than 25,000 inhabitants have been excluded.

Elkton series.—Light-gray to white surface soils, with mottled whitish gray and yellow subsoils, overlying gravel and coarse sands.

Gadsden series.—Gray soils, with subsoils of similar texture occupying gentle slopes and depressions and formed by wash or creep from higher areas. This series occurs in rather local development, particularly in Florida, southern Georgia, and Alabama. They are very productive soils and well adapted to tobacco. No heavy members of the series have been encountered, and it is doubtful if any exist.

Guin series.—Gray soils with brown to yellowish-red subsoils, occurring as rolling and hilly uplands. Intermediate series between the Norfolk and Orangeburg series. Owing to the rather rough topography these soils have not been developed as much as either of the other series, although they seem capable of producing better crops than they do now.

Houston series.—Dark-gray or black calcareous prairies. One of the most productive series for Upland cotton and well adapted to alfalfa and other forage crops.

Laredo series.—Gray to light-brown calcareous soils with gray subsoils. Good cotton, corn, and sugar cane soils, and especially adapted to the early production of vegetables—cabbage and onions in particular.

Lufkin series.—Light-colored soils with heavy mottled gray and yellow subsoils. The soils of this series have only a moderate degree of productivity.

Montrose series.—Gray soils with heavy plastic mottled yellow subsoils. These soils are in part poorly drained, but where cultivable they produce moderate yields of cotton and corn.

Myatt series.—Gray soils with mottled yellow, gray, and whitish subsoils occurring in poorly drained areas around heads of streams and intermediate between uplands and bottom lands. This series seems to be of local extent and but little developed.

Norfolk series.—Light-colored soils with yellow sand or sandy clay subsoils. This series contains some of the most valuable truck soils of the Atlantic and Gulf Coast States, and certain members of the series are adapted under certain climatic conditions to wheat, grass, tobacco, and fruit.

Oktibbeha series.—Gray soils with brown to yellowish-brown heavy subsoils related to Houston series in origin. The soils of this series are distinctly inferior to the soils of the Houston series and, as they appear to cover large areas in Mississippi and Alabama, present a difficult problem in soil improvement.

Orangeburg series.—Light-colored soils with red sandy clay subsoils. This series constitutes some of the best cotton soils of the

South, and certain members of the series are particularly adapted to tobacco.

Portsmouth series.—Dark-colored soils with yellow or mottled gray sand or sandy clay subsoils. Where drainage is adequate this series is adapted to some of the heavier truck crops, to small fruits, and to indian corn.

Sassafras series.—Yellowish-brown surface soils with reddish-yellow to light-orange subsoils overlying gravel beds.

Susquehanna series.—Gray soils with heavy red clay subsoils which become mottled and variegated in color in the deep subsoil. Only one member of this series, the sandy loam, has been developed to any considerable extent. This one is used for fruit and general farm purposes, but the other members are particularly refractory and difficult to bring into a productive state.

Webb series.—Brown to reddish-brown soils with reddish-brown to red subsoils, a semiarid prototype of the Orangeburg series. The soils of this series have not been used to any great extent, owing to lack of irrigation facilities.

Wickham series.—Reddish or reddish-brown terrace soils overlying reddish, micaceous heavy sandy loam or loam subsoils. The soils of this series have a relatively high productivity for general farm crops.

Wilson series.—Dark-gray prairie soils with mottled gray subsoils. The clay member of this series is a strong soil devoted to general farming, with cotton as the leading crop. The other members are used for cotton, but are inclined to be droughty.

RIVER FLOOD PLAINS.

Congaree series.—Brown or reddish-brown soils found along Piedmont streams and representing wash from Cecil soils. Valuable and dependable corn soils, but too low and moist for cotton.

Huntington series.—Dark-brown to yellowish-brown soils occurring along streams in the Allegheny plateaus. Both the general farm crops and truck crops thrive on these soils.

Miller series.—Brown to red alluvial soils formed from the reworking of materials derived from the Permian Red Beds. Very productive soils suitable for cotton, corn, sugar cane, alfalfa, and vegetables; especially adapted to peaches.

Ocklocknee series.—Gray to yellowish-brown soils found along streams in Coastal Plain Georgia, Alabama, and Mississippi. Cotton, corn, and pasturage are the leading products.

Wabash series.—Dark-brown or black soils subject to overflow. Very productive soils used for cotton, sugar cane, corn, wheat, oats, grass, alfalfa, sugar beets, and potatoes and other vegetables.

Waverly series.—Light-colored, alluvial soils subject to overflow. Less productive than the Wabash soils, but adapted to the same wide range of crops.

Wheeling series.—Brown to yellowish-brown soils occurring on gravel terraces along streams issuing from glaciated regions. Excellent soils for general farming, and fruit and truck growing.

PIEDMONT PLATEAU.

Cecil series.—Gray to red soils with bright-red clay subsoils, derived from igneous and metamorphic rocks. Constituting by far the larger portion of the province, these soils are well adapted to and used for cotton, export tobacco, and fruit, and the lighter members for truck crops. As a rule they are not highly developed, but where properly handled the heavier members produce excellent crops of corn and grazing and hay grasses.

Chester series.—Gray to brown surface soils with yellow subsoils, derived principally from schists and gneisses. The most valuable soils of the province for wheat and corn and good for certain fruits. The most highly developed soils of the Piedmont plateau.

Penn series.—Dark Indian-red soils with red subsoils, derived from red sandstones and shales of Triassic age. Excellent soils for general farm crops, particularly wheat, corn, and hay.

APPALACHIAN MOUNTAINS AND PLATEAU.

Dekalb series.—Brown to yellow soils with yellow subsoils, derived from sandstones and shales. Soils of this series are used, according to texture, elevation, exposure, and character of surface, either for the production of hay, for pasture, or for orchard and small fruits.

Fayetteville series.—Grayish-brown to brown soils with yellowish or reddish-brown subsoils. Adapted to apples, grapes, and small fruits, and give moderate yields of general farm crops.

Porters series.—Gray to red soils with red clay subsoils, derived from igneous and metamorphic rocks. This is the greatest mountain fruit series of the eastern United States. It is also used for general farming.

Upshur series.—Brown to red soils with red subsoils, derived from sandstones and shales. Somewhat more productive than the Dekalb soils. Used for cotton, corn, wheat, and forage crops.

LIMESTONE VALLEYS AND UPLANDS.

Clarksville series.—Light-gray to brown soils with yellow to red subsoils, derived mainly from the St. Louis limestone. While not as strong as the Hagerstown soils, this is a valuable series. Apples and peaches are commercially important. Tobacco is a leading product. General farming is firmly established in many extensive regions.

Cumberland series.—Brown surface soils, derived from thin deposit of sedimentary material overlying residual limestone subsoils. Used for cotton and other general farm crops, truck, and fruit.

Decatur series.—Reddish-brown to red soils with intensely red subsoils. Intermediate in value between the two series just described. Cotton, corn, wheat, oats, forage crops, bluegrass, and peaches are the leading crops.

Hagerstown series.—Brown to yellowish soils with yellow to reddish subsoils, derived from massive limestone. Among the most productive soils of the eastern United States. Fine wheat and general farming soils, and the seat of important apple orcharding interests. Bluegrass is indigenous.

GLACIAL AND LOESSIAL REGIONS.

Marshall series.—Dark-colored upland prairie soils. The principal soils of the great corn belt belong to this series, while in the Northwest the finest wheat soils are found in this group. They are among the best general farming soils of the entire country.

Miami series.—Light-colored upland timbered soils. The different members of this series are considered good general farming soils and have in addition special adaptations for truck, fruit, small fruit, and alfalfa.

Volusia series.—Light-colored soils with yellowish subsoils, derived by feeble glacial action from sandstones and shales. The soils of this series are adapted to the production of potatoes, grass, oats, buckwheat, and in the less elevated positions to corn.

GLACIAL LAKE AND RIVER TERRACES.

Clyde series.—Dark-colored swamp soils formed from reworked glacial material deposited in glacial lakes. A special use for these soils is the production of sugar beets, while general farm crops, truck, and canning crops are grown extensively.

Dunkirk series.—Light-colored reworked glacial material occurring as terraces around lakes and along streams. Good general farming soils and especially adapted to grapes and other fruits.

Fargo series.—Black calcareous soils rich in organic matter formed by deposition of material in glacial lakes. This is the most important group of soils in the Red River Valley, and includes exceptional soils for the production of wheat, barley, and flax. While these are the chief crops at present, the soil adaptations are by no means limited to small grain production. Timothy and vegetables may become more important products with the development of markets.

Hudson series.—Light-brown to yellowish-brown soils, with drab to yellowish subsoils.

Merrimac series.—Brown terrace soils underlain by gravel formed principally of reworked glaciated crystalline rocks. Leachy soils of low general farming value, but especially adapted to trucking and apple orcharding in some sections.

Sioux series.—Dark-colored soils resting on dark or light-colored subsoils, with gravel beds usually within 3 feet of the surface. The crops produced on soils of this series range from early short-seasoned truck crops through special crops like alfalfa and sugar beets to the wide variety of general farm crops produced in the Central West.

Superior series.—Gray and red soils with red subsoils, formed from reworked glacial material deposited in glacial lakes. Not extensively developed, but known to include fine types for clover, timothy, and small fruits.

Vergennes series.—Light-colored soils, with gray or whitish subsoils, derived from Champlain clays or lighter deposits over these clays. This series includes the best hay and apple soils of the Champlain Valley. A wide variety of tillage crops is grown, but cultivation of the heavier members of the series is very difficult.

RESIDUAL SOILS OF THE WESTERN PRAIRIE REGION.

Crawford series.—Brown soils with reddish subsoils, derived from limestones. The soils of this series range from rough areas suited mainly for pastures to fertile general-farming, fruit-growing, and trucking soils.

Oswego series.—Gray or brown soils, derived from sandstones and shales. The lighter members of this series are adapted to corn, oats, potatoes, truck, and fruit; the heavier to these crops and wheat.

Vernon series.—Brown to red soils typical of the Permian formation. Soils of this series show a wide adaptation according to texture. General farm crops, including cotton, corn, wheat, Kafir corn, and sorghum are the leading products. Small fruit, peaches, and truck are grown to some extent and are capable of marked extension.

GREAT BASIN.

Bingham series.—Porous dark or drab colluvial and alluvial soils underlain by gravel or rock, occupying lower mountain slopes. The lighter types when irrigable are devoted to orchard fruits, the heavier types to alfalfa and sugar beets.

Jordan series.—Light to dark-colored lacustrine deposits. These soils are utilized principally in the production of alfalfa, sugar beets, truck crops, and grains under favorable conditions for irrigation and drainage, but considerable areas covered by some of the members of this series are not utilized on account of the accumulation of alkali, poor drainage, or because of their drifting character.

Malade series.—Dark-colored alluvial soils underlain by light-colored sands, sandy loams, or heavy reddish material. These soils are devoted chiefly to sugar beets, alfalfa, grain, and some orchard fruits.

Redfield series.—Red soils consisting of colluvial and alluvial materials derived from red sandstones and other rocks. The lighter members are adapted to the production of alfalfa, grain, and general farm crops when irrigable and well drained. The heavier members, as far as encountered, are poorly drained and have not been developed.

Salt Lake series.—Dark-colored soils underlain by stratified sediments of lacustrine origin. These soils, as far as encountered, occupy very low, flat positions around the lake and have not been developed to any extent.

NORTHWESTERN INTERMOUNTAIN REGION.

Bridger series.—Dark-colored soils with sticky yellow subsoils, of colluvial and alluvial origin. These soils generally occupy elevated foot slopes or sloping valley plains and have not been developed to a great extent. They are most extensively used for the production of grain and when irrigated are utilized in the production of alfalfa and other hay crops and under favorable climatic conditions are adapted to fruits.

Gallatin series.—Light to dark-colored soils with yellowish to dark compact subsoils, of recent alluvial origin from basaltic and volcanic rocks. These soils generally occupy low positions, very frequently poorly drained, often subject to overflow, and have not been extensively developed for agricultural purposes. They are used chiefly for grazing and to some extent in the production of hay, grains, and in some sections for vegetables.

Yakima series.—Ash-gray to light-brown soils derived principally from ancient lake sediments consisting of an admixture of volcanic dust and basaltic, andesitic, and granitic materials. Certain members of this series have been very successfully developed for hop culture, alfalfa, grass, grain, and fruit, while other members of the series, owing to their elevated position and general rough character, have not been developed at all.

ROCKY MOUNTAIN VALLEYS, PLATEAUS, AND PLAINS.

Billings series.—Compact adobelike gray to dark or brown soils and subsoils, formed mainly by reworking of sandstones and shales and occupying old elevated stream terraces. This is an important series adapted to alfalfa and general farm crops and stock raising; also used to a considerable extent in the production of sugar beets.

Colorado series.—Light-gray to reddish-brown soils and subsoils, derived from colluvial wash. Where irrigable these soils are important soils in the production of alfalfa, sugar beets, melons, and to a limited extent, fruits. A number of the soils of the series, however, are so situated as not to be susceptible to irrigation, and have not been developed for agricultural purposes.

Finney series.—Brown to nearly black soils derived from glacial material underlain by lighter colored subsoils. The heavier soils may be dry farmed to advantage and would become very productive with irrigation. The lighter soils have a broken surface, are porous and easily drifted by the wind. They are best adapted to grazing.

Fruita series.—Reddish-brown soils, formed by reworking of sandstones and shales, occurring as stream terraces. When well drained and free from alkali the members of this series are admirably adapted to the production of choice fruits, alfalfa, sugar beets, grains, and truck crops.

Laramie series.—Dark-colored soils, with light-colored gravelly subsoils, derived from colluvial mountain wash. These soils have not been extensively developed owing to their elevation, and are used principally for grazing purposes.

Laurel series.—Light-gray to black soils, underlain by river sands or gravels, occurring in flood plains along streams. Under favorable moisture conditions these are fertile soils, adapted according to locality to corn, alfalfa, sugar beets, and truck crops, but the areas are often subject to overflow, and in some cases can not be drained.

Mesa series.—Light-gray to brown soils derived from old flood-plain deposits, now elevated to form mesa lands. Where these soils have been developed and are susceptible of irrigation they are used mainly for alfalfa and sugar beets. One member of the series has been quite extensively and very successfully used for the production of apples and peaches.

Morton series.—Brown residual soils, derived from sandstones and shales. The soils lie in the semiarid region, and give good yields of wheat, flax, oats, and potatoes when rainfall is sufficient.

San Luis series.—Reddish-brown gravelly soils, formed from lacustrine sediments of volcanic rock materials. On account of the position and the danger from alkali these soils have not been successfully developed, but have been used mainly for pasturage and forage crops.

Wade series.—Brown to dark-brown alluvial soils, formed by reworking of sandstones and shales. Used for oats, flax, millet, and wheat.

ARID SOUTHWEST.

Gila series.—Light to dark brown soils of flood-plain alluvium underlain at varying depths by coarse sands and gravels. Under favorable irrigation and drainage conditions the members of the Gila series are adapted chiefly to the production of alfalfa, potatoes, truck, and root crops.

Imperial series.—Light-colored or reddish soils formed from old marine or lacustrine sediments modified by more recent deposits and underlain to great depths by heavy material. These soils are particularly adapted to alfalfa, sorghum, and other forage crops.

Indio series.—Light-colored soils usually underlain by coarser sands and gravels, formed by colluvial and alluvial wash from granitic rocks, mingled with some shale and sandstone. These soils are adapted to fruit, truck crops, sweet potatoes, melons, and alfalfa under favorable conditions of irrigation and drainage.

PACIFIC COAST.

Anderson series.—Reddish-gray or light-red alluvial soils occupying principal valley plains and the bottoms of intermittent streams. Generally gravelly. The soils of this series when not too gravelly are adapted to the production of peaches, pears, prunes, and small fruits, but are, in so far as mapped at present, inextensive types of secondary agricultural importance.

Fresno series.—Light-colored soils with light-gray, ashy subsoils and alkali-carbonate hardpan, derived from old alluvial wash. Where protected from alkali accumulations these soils have been very successfully used for vineyards and raisin grapes, and are particularly adapted to almonds, peaches, and apricots.

Hanford series.—Recent alluvium of flood or delta plains derived from a variety of rocks. The light-textured soils are light in color and the heavy-textured soils are dark in color. The lighter members of the series are adapted to the same class of fruits and raisin grapes as the Fresno series. The heavier members of this series, however, are better adapted to alfalfa, sugar beets, celery, asparagus, and other truck crops.

Maricopa series.—Loose, dark-colored soils derived from unassorted colluvial or partially assorted alluvial materials, generally derived from granitic or volcanic rocks. There are two heavy members of this series upon which alfalfa, grain, and sugar beets are important crops. The lighter members, when occupying positions so that they can be irrigated, are adapted to citrus and deciduous fruits; also vines.

Oxnard series.—Dark-colored alluvial or colluvial soils derived from higher lying areas of sandstones and shales. Members of this series are used to a very large extent for sugar beets and lima beans, and, where irrigation is not practicable, extensively used for grain.

Placentia series.—Reddish soils derived largely from the weathering of alluvial and colluvial deposits, generally underlain by heavy compact red material with an impervious adobe structure. Large areas of these soils are devoted to dry farming of grain and occur throughout southern California and in some of the coastal valleys, viz, Bakersfield, Salinas, and San Jose. There are extensive areas under irrigation, which are valuable for producing both deciduous and citrus fruits. The heavier members of this series have been more successfully used for grain production in southern California. They seem particularly well adapted to English walnuts and olives. The soils are usually well drained. The English walnut does not thrive on poorly drained soils.

Redding series.—Ancient alluvial valley deposits of red and deep-red color, generally gravelly. Heavy red subsoils with hardpan. The soils of this series when not carrying an excess of cobbles or underlain at shallow depths by hardpan are excellently adapted to the production of choice peaches and small fruits.

Sacramento series.—Gray alluvial soils consisting of recent stream sediments. The lighter members of this series are used mainly for the production of prunes, pears, and peaches. The members of the series having a medium texture are adapted to sugar beets, alfalfa, and prunes. The heavier members are at present poorly drained and have not been highly developed, being used mostly for grain and grazing.

Salem series.—Residual, alluvial, or colluvial soils, either red or dark in color, derived from rocks of basaltic, schistose, crystalline, or arenaceous character. These soils, so far as they have been encountered, seem particularly adapted to hops, potatoes, and have been used to some extent for apples, peaches, and grain. They have not been very highly developed in the areas in which they have been encountered.

San Joaquin series.—Compact red soils and subsoils derived from old marine sediments, usually underlain by red hardpan. These soils have been used almost exclusively for dry farming to grain on account of the general occurrence of hardpan and very stiff and impervious subsoils. Recently in the Sacramento area some members of this series have been very successfully used for the production of the Tokay grape and strawberries.

Sierra series.—Light-gray to red and frequently gravelly soils, often underlain by red adobe. Members of this series constitute some of the most valuable deciduous fruit soils of the foothills in northern California.

Sites series.—Residual and colluvial soils of reddish-gray or dark-brown color, derived from sandstones, shales, conglomerates, and volcanic or altered material occupying low rolling foothills and their valley slopes, usually underlain at shallow depths by sandstones, congomerates, or heavy subsoils. The Sites loam and clay loam adobe are the important soils of this series and are productive, but owing to their position are generally unirrigable and adapted to dry farming to grains.

Stockton series.—Brown to black soils with heavy yellow subsoils, derived from old alluvial sediments. These soils have been used principally for the production of grain. The lighter members of this series have been adapted to fruit.

Willows series.—Brown soils consisting of wash deposited by intermittent foothill streams. These soils have been used almost exclusively for dry farming grain crops. Large ranches are being broken up and brought under irrigation, and alfalfa and sugar beets are likely to prove the most important crops.

Area of the soil series and the combined area of the miscellaneous soils of each of the provinces.

Province and series.	Acres.
Atlantic and Gulf Coastal Plains:	
Norfolk series	9,612,882
Orangeburg series	3,486,464
Houston series	2,326,016
Portsmouth series	1,729,160
Susquehanna series	1,495,990
Lufkin series	1,375,808
Sassafras series	497,344
Guin series	455,104
Elkton series	184,852
Webb series	184,512
Wilson series	175,040
Myatt series	86,912
Gadsden series	78,528
Oktibbeha series	72,448
Montrose series	64,768
Bastrop series	58,432
Laredo series	55,040
Crockett series	29,504
Wickham series	17,664
Miscellaneous soils	3,627,198
Total for province	25,618,666
River flood plains:	
Wabash series	1,861.497
Waverly series	882,240
Miller series	595,904
Huntington series	258,496
Ocklocknee series	236,416
Congaree series	183,232
Wheeling series	20,032
Miscellaneous soils	4,023,430
Total for province	8,061,247
Piedmont Plateau:	
Cecil series	5,191,746
Penn series	726,364
Chester series	692,698
Miscellaneous soils	660,990
Total for province	7,271,798
Appalachian mountains and plateau:	
Dekalb series	2,864,320
Porters series	1,664,528
Fayetteville series	179,968
Upshur series	163,904
Miscellaneous soils	1,494,289
Total for province	6,367.009
Limestone valleys and uplands:	
Clarksville series	3,623,322
Hagerstown series	1,889,884
Limestone valleys and uplands—Continued.	
Decatur series	190,464
Cumberland series	69,376
Miscellaneous soils	279,880
Total for province	6,052,926
Glacial and loessial:	
Marshall series	8,057,686
Miami series	7,422,760
Volusia series	1,057,570
Miscellaneous soils	5,879,816
Total for province	22,417,832
Glacial lake and river terraces:	
Clyde series	1,211,332
Dunkirk series	880,592
Fargo series	638,208
Merrimac series	506,660
Sioux series	423,610
Superior series	229,184
Vergennes series	169,408
Hudson series	22,144
Miscellaneous soils	1,010,744
Total for province	5,091,882
Residual soils of the western prairie region:	
Vernon series	543,296
Crawford series	541,524
Oswego series	488,141
Miscellaneous soils	252,889
Total for province	1,825,850
Great Basin:	
Jordan series	349,216
Bingham series	206.434
Salt Lake series	162,734
Redfield series	104,724
Malade series	36,096
Miscellaneous soils	146,396
Total for province	1,005,600
Northwestern intermountain region:	
Yakima series	628,182
Gallatin series	400,808
Bridger series	62,016
Miscellaneous soils	364,422
Total for province	1,455,428

Area of the soil series and the combined area of the miscellaneous soils of each of the provinces—Continued.

Province and series.	Acres.
Rocky Mountain valleys and plains:	
Colorado series	722,240
Morton series	464,640
Laurel series	363,584
San Luis series	348,040
Billings series	173,120
Laramie series	105,472
Finney series	60,672
Mesa series	59,136
Wade series	57,792
Fruita series	4,480
Miscellaneous soils	585,664
Total for province	2,989,840
Arid southwest province:	
Imperial series	516,416
Gila series	208,875
Indio series	171,904
Miscellaneous soils	233,960
Total for province	1,131,155
Pacific coast province:	
Hanford series	622,321
Maricopa series	585,843
San Joaquin series	530,758
Placentia series	518,431
Oxnard series	387,462
Fresno series	304,405
Sierra series	247,081
Willows series	227,072
Salem series	181,824
Sacramento series	173,824
Stockton series	163,358
Redding series	71,488
Sites series	38,336
Anderson series	18,048
Miscellaneous soils	578,680
Total for province	4,593,881
Total for United States	93,828,114

GENERAL CHARACTER OF THE SOIL PROVINCES AND SOIL SERIES, AND THE RELATIVE VALUE OF THE DIFFERENT SOIL TYPES.

ATLANTIC AND GULF COASTAL PLAINS.

The Atlantic and Gulf Coastal Plains together constitute one of the most important physiographic divisions of the United States. The Atlantic Coastal Plain extends from the New England States southward to the Florida Peninsula, where the Gulf Coastal Plain begins, and extends thence westward to the Mexican boundary line. It is, however, discontinuous, being interrupted by the alluvial bottoms of the Mississippi River. From the coast the Atlantic Plain extends inland to the margin of the Piedmont Plateau—that is, to a line passing through Trenton, Baltimore, Washington, Richmond, Raleigh, Columbia, Augusta, and Macon. In its northern extension it is represented by a narrow belt, but widens in New Jersey and attains its maximum breadth of about 200 miles in North Carolina. The Gulf Plain extends up the Mississippi to the mouth of the Ohio, its inner boundary line passing through or near Montgomery, Iuka, Cairo, Little Rock, Texarkana, Austin, and San Antonio.

The surface is that of a more or less dissected plain marked by few hills, slightly terraced with bluffs along streams. The inner margin of the Coastal Plain is usually from 200 to 300 feet above tidewater, but sometimes rises to 500 feet. The drainage here is usually well established and the surface is rolling to hilly, and consequently carved and eroded. There is a wide belt bordering the coast where the elevations are mostly under 100 feet. North of the James River, where the Coastal Plain is narrow and deeply indented with tidal estuaries, drainage is usually well established and the surface is rolling, but in the broad southern extension, where the seaward slope is hardly more than 1 foot to the mile, drainage is apt to be deficient. Here rain water often remains upon the surface for a considerable time, although the conditions are not comparable with those of a true swamp. The soils in this level section, while composed largely of sand, are compact, usually deficient in organic matter, and not very productive. Many of the flat interstream areas possess such poor drainage that true swamps, such as the Dismal and Okefenokee, have been formed. Near the coast and along the tidal estuaries extensive marshes, separated from the ocean by sand barriers, are found.

The Coastal Plain is made up of unconsolidated gravels, sands, and sandy clays, with less frequent beds of silts and heavy clays. The deposits on the Atlantic coast have been derived mainly from the erosion of the Piedmont Plateau and other inland areas, while the deposits on the Gulf coast have been derived mainly from transported glacial material and from western plains. The materials have been transported and deposited beneath the sea and subsequently exposed by the uplift of the ocean floor. In the more northern parts of the Coastal Plain, and even as far south as Virginia, the character of the deposits has been modified by glacial action and the flooded condition of the streams resulting from the melting of the ice.

The Coastal Plain deposits range in age from Cretaceous to Recent. Although extensive areas of the older sediment are exposed at the surface to form soils, still by far the greater part of the materials is Quarternary or Recent in age.

The soils are for the most part composed of sands and light sandy loams, with occasional deposits of silts and heavy clays. The heavy clays are found principally near the inner margin of the Coastal Plain. The silts, silty clays, and black calcareous soils, upon which the rice and sugar cane industries of southern Louisiana and Texas are being so extensively developed, have no equivalents in the Atlantic division.

The aggregate area of all the soils surveyed in this province is 25,613,666 acres.

Bastrop series.

The Bastrop series represents old alluvial material brought down by streams from the Permian Red Beds and deposited as terraces now almost entirely above overflow. The soils are brown with reddish-brown to red subsoils and constitute very fine farming lands.

The Bastrop silt loam is devoted to cotton and corn. Alfalfa can be successfully grown. Melons and potatoes do well. Some of the type is overflow land and is very productive. The sandy loam is a light river-bottom soil suited to truck and melons, although cotton and corn are extensively grown. The soil needs fertilization with green manure. It has good drainage. The clay is a strong, heavy soil, sometimes subject to overflow, and requiring care in cultivation.

It is especially adapted to corn, yielding large crops, and does well also with cotton. The fine sandy loam in Bastrop and Wilson counties, Tex., is a very productive soil adapted to a wide range of crops. It suffers to some extent from drought, but with careful management to preserve soil moisture it would be a very valuable trucking soil. If irrigated, the highest possibilities of agricultural development could be attained. Cotton, corn, and sorghum give large yields. Oats make a thrifty growth, and alfalfa, grown to some extent, gives good returns. Pecans are indigenous and could be grown on a commercial basis in the river bottoms. Melons, potatoes, peanuts, and vegetables are grown and do exceptionally well. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Bastrop series.

Soil name.	State in which each type has been found.	Total area.
		Acres.
Bastrop sandy loam	Texas	7,680
fine sandy loam	do	32,320
silt loam	do	[a]6,080
clay	do	12,352
Total		58,432

[a] Of this amount 1,216 acres in the Austin area mapped as Yazoo sandy loam.

Crockett series.

The Crockett series occurs as isolated prairies in the timbered part of Texas. The soil is gray to dark gray and sometimes almost black in color, while the subsoil is mottled red, gray, and black, the red mottling being the distinguishing characteristic. This series may be considered as representing a gradation from the Houston series, or black prairie soils, to the mottled red clays of the Susquehanna series.

Soils of the Crockett series, being derived from slightly calcareous materials, are productive. The clay loam, the most extensive type, produces yields of cotton above the average and is successfully used for other general farming crops. The loam and fine sandy loam produce fair yields of cotton and corn. The gravelly loam is one of the earliest soils in the region in which it occurs and is adapted to early vegetables and trucking. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Crockett series.

Soil name.	State in which each type has been found.	Total area.
		Acres.
Crockett gravelly loam	Texas	3,008
fine sandy loam	do	4,416
loam	do	640
clay loam	do	21,440
Total		29,504

Elkton series.

The Elkton series consists of light-gray to white surface soils with mottled whitish-gray and yellow subsoils. Gravel or coarse sand is usually found at a depth of 2½ to 3 feet below the surface, and is usually saturated with water. This series is closely associated with the Sassafras, and the difference is due to the intermittent wetting and drying to which the Elkton soils have been subjected, causing them to become very much lighter in color and much lower in agricultural value.

The silt loam is much more extensively developed than the other members of this series. It produces good wheat and grass, but poor average crops of tomatoes and corn. The soil is much benefited by turning under green manures and by liming. It should be devoted principally to growing grass and forage crops in connection with stock raising.

The other members of the series are usually in need of drainage, and this as well as liming must be resorted to before the best results can be secured. They are best suited to grass and forage crops. The acreage of the different types so far encountered is as follows:

Area and distribution of the soils of the Elkton series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Elkton sandy loam	Maryland	9,280
fine sandy loam	Virginia	14,656
loam	Maryland	2,624
silt loam [a]	Delaware, Maryland, New Jersey, Pennsylvania	158,292
Total		184,852

[a] Mapped in the Chester County area, Pennsylvania, as the Portsmouth silt loam.

Gadsden series.

The Gadsden series includes dark-gray soils found upon gentle slopes or undulations adjacent to streams and upon level or depressed areas in the uplands. Their formation is due largely to the peculiar topographic conditions resulting from the sinking of the limestones which underlie, in some of the areas, the materials from which the Norfolk and Orangeburg soils have been derived. They may be considered as colluvial soils formed by the creeping or washing of material from higher lying areas. The series is very incomplete, only the sand, sandy loam, and loam members having been encountered.

The Gadsden series is of minor importance as compared with the more extensive Norfolk, Orangeburg, and Lufkin soils, but constitutes valuable farming lands. The sand, which is the most extensive type, is very productive, and of special use in the growing of Florida Sumatra wrapper tobacco. The sandy loam, of limited extent, likewise produces a fine grade wrapper and is good for cotton and corn. Sugar cane does well on the lower lying areas. The loam member, a well-drained, productive soil, is adapted to cotton, corn, and forage crops. Indicated adaptations are truck and tree fruits. The acreage of the different types so far encountered is as follows:

Area and distribution of the soils of the Gadsden series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Gadsden sand	Florida, Georgia	57,344
sandy loam	Florida	6,592
loam	Mississippi	14,592
Total		78,528

Guin series.

The Guin series consists of gray soils with brown to yellowish-red subsoils. This series is closely related to the Orangeburg and the Norfolk series and in position and characteristics is intermediate between the two. It is derived from unconsolidated deposits, principally of the Lafayette formation, and is found near the inner border of the Coastal Plain in northeastern Mississippi and northwestern Alabama. The generally broken and hilly character of the surface renders it of low value for general agriculture.

The soils of the Guin series are still largely in forest and have been improved very little. Cultivated areas produce moderate yields of corn and cotton. It is thought that these soils would make good land for peach culture. The acreage of the different types so far encountered is shown in the following table:

Area and distribution of the soils of the Guin series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Guin stony sandy loam	Alabama	28,032
gravelly sandy loam	do	69,056
fine sandy loam	Alabama, Mississippi	358,016
Total		455,104

Houston series.

The Houston series occurs principally in the black, calcareous prairie regions of Alabama, Mississippi, and Texas. The soils are characterized by a large percentage of lime, especially in the subsoil, which in some of the types consists of white, chalky limestone. The series has been derived from the weathering of calcareous clays, chalk beds, and " rotten " limestones, all of late Cretaceous age. In some localities remnants of later sandy and gravelly deposits have been mingled with the calcareous material, giving rise to the gravelly and loam members of the series.

The soils of the Houston series constitute the fertile black prairies of the Gulf States, and are not found east of Alabama. They are without question the most productive upland soils of the Gulf Coastal Plain, a fact mainly due to their calcareous nature. The Houston black clay, locally known as "black waxy land," is the most extensively developed soil of the series. In the sections where it occurs it is the best cotton soil. In the past it has been used chiefly in the production of this crop, but, being well adapted to alfalfa, in recent years the acreage in this legume has steadily increased. In its virgin state it supported a heavy growth of native prairie grasses and in some sections hay and pasturage are still its important products. The Houston clay, while not as valuable land as the black clay, has a special adaptation for alfalfa, and produces good yields of cotton and the other staple crops. In the vicinity of San Antonio, Tex., there is associated with the Houston black clay a black clay loam soil that is good cotton, corn, and sorghum land, and which, under irrigation, could be profitably used for some truck crops. This type, so far as the soil survey has shown, is one of comparatively limited occurrence. The Houston loam, on the contrary, has been mapped in a number of areas and though not as highly esteemed as the heavier members of the series is considered a good soil for cotton, corn, and sorghum. Being lighter textured, it is less plastic and sticky and may be worked under a wider range of moisture conditions. The gravelly member of the series lies in a semiarid country and is too high for irrigation. Little of it is under cultivation, and its principal value is as pasture. The Houston chalk represents areas where erosion has exposed the Selma chalk, which gives rise to the Houston series. Areas mapped as this last-mentioned type are of little present agricultural use, though by judicious handling they may be improved and can then be utilized for the crops mentioned as doing well on the more important soils of the series. The acreage of the different types so far as mapped is shown in the following table:

Area and distribution of the soils of the Houston series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Houston gravelly clay	Texas	148,416
loam[a]	Oklahoma, Texas	239,296
black clay loam	Texas	54,272
black clay[b]	Alabama, Oklahoma, Texas	1,265,304
clay[c]	Alabama, Kansas, Louisiana, Mississippi, Texas	610,664
chalk	Mississippi	8,064
Total		2,326,016

[a] The soils mapped as Houston silt loam and Houston clay in the Paris area, Texas, are Houston loam.

[b] The soil mapped as Houston clay in the Anderson County area, Texas, is Houston black clay.

[c] The soil mapped as Houston black clay in Macon County area, Alabama, is the Houston clay.

Laredo series.

The Laredo series consists of gray to light-brown calcareous soils with gray calcareous subsoils. They occur as a terrace along streams in south Texas and also constitute the principal soils of the Rio Grande delta above overflow. They are made up largely of material which has been brought down from the calcareous and more arid parts of the State. They are seldom or never overflowed, and constitute very valuable farming lands when irrigated.

Laredo silty clay loam, mapped in Brownsville area, Texas, is a very productive soil and well adapted to growing early vegetables. Profitable yields of corn, cotton, and sugar cane are obtained. Fair yields of both cotton and corn are often secured in a favorable season without irrigation. Lettuce, melons, cauliflower, beets, peas, cabbage, onions, eggplant, cucumbers, tomatoes, carrots, and both sweet and Irish potatoes are all profitably grown under irrigation. Cabbage is the principal crop and the average yield is about 18,000 pounds per acre; the average yield of onions is about the same. Irish potatoes yield from 60 to 70 bushels and sugar cane 25 to 30 tons per acre. The clay loam, also recognized in the Laredo area, Texas, is well adapted to the production of onions, giving an average yield of about 20,000 pounds per acre. Alfalfa has been grown under irrigation, though the stand continues good for only one year. Cabbage, beets, and Irish potatoes do well. Sorghum, cowpeas, and sweet potatoes give good returns. The Laredo silty clay is found in the Brownsville area, Texas. Some alkali areas are found in this soil, but yield readily to treatment. When well drained and put under irrigation good yields of corn, cotton, sugar cane, lettuce, cauliflower, tomatoes, beans, peas, cabbage, and other vegetables are produced. The silt loam has been mapped so far only in the Laredo and Brownsville areas, Texas. This type of soil gives the best returns under irrigation. It is well adapted to onions, which give an average yield of 18,000 to 20,000 pounds per acre. Cotton has been grown under irrigation and where irrigated sweet potatoes produce 150 to 200 bushels per acre. Some corn has been grown on the irrigated land, as have cabbages, beets, turnips, and Irish potatoes. Cabbage yields about 13,000 pounds to the acre. Cowpeas do well on both the unirrigated and irrigated soils.

The clay is covered by a dense growth of mesquite and other native vegetation. It is a productive soil and free from alkali accumulations. It was recognized in the Laredo area, Texas, where it is utilized exclusively as pasture land for stock. If irrigated it would produce many varieties of early vegetables. In the Brownsville area it is used for producing rice, which gives a return of 12 sacks; cotton, which averages 1 bale; and corn, about 30 bushels per acre. Beans, peas, cauliflower, cabbage, tomatoes, lettuce, cowpeas, Irish potatoes, and some celery have been produced on this soil. The acreage of the different types so far encountered is as follows:

Area and distribution of the soils of the Laredo series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Laredo silt loam	Texas	16,768
clay loam	do	704
silty clay loam	do	33,216
silty clay	do	448
clay	do	3,904
Total		55,040

Lufkin series.

The Lufkin series is characterized by gray surface soils and heavy, very impervious, plastic gray and mottled subsoils. The difference between the texture of the surface soil and that of the subsoil is very marked, especially in the sandy loam members.

A large part of the area of the Lufkin series of soils is still covered with forest, and from the character of growth the land is known as "swamp" or "post-oak" land.

These soils in most of the areas so far surveyed are generally lower in agricultural value than the Norfolk and Orangeburg soils, but in some parts of Texas the sandy loam forms the principal agricultural soil, and, without fertilization, produces yields of cotton that are even better than those secured on the Norfolk soils. The sandy loam is also adapted to potatoes, cucumbers, and other truck. Lavaca County, Tex., is the only area surveyed in which the Lufkin sand has been found. This soil is a deep sandy type, with a tendency to drought, and is generally poor, but has a special use in the production of sweet potatoes, and offers opportunity for the development of the early trucking industry. The fine sand is used for cotton and corn. It is better adapted to truck crops and to peaches. Cotton and corn, perhaps, do better on the fine sandy loam, though this soil will be found to be suited to other crops, among which should be included certain kinds of truck and fruit. Nearly 400,000 acres of the clay has been mapped, this being the most extensive soil of the series. While a difficult soil to handle, it has been made to produce as high as 1 bale of cotton to the acre. Grass also does well and it offers opportunities for stock raising. The loam is unimportant in extent, but is a good soil, as indicated by the yields of corn and cotton. It is adapted also to truck crops and strawberries. The acreage of the types, so far encountered, is shown in the table on the following page.

Area and distribution of the soils of the Lufkin series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Lufkin gravelly loam	Texas	58,112
sand	do	63,936
fine sand	do	229,568
sandy loam	do	362,944
fine sandy loam [a]	do	226,752
loam	do	5,376
silt loam	Mississippi	55,808
clay [b]	Alabama, Louisiana, Mississippi, Texas	373,312
Total		1,375,808

[a] The area mapped as Lufkin fine sandy loam in the Austin area, Texas, is the Susquehanna fine sandy loam.

[b] The area mapped in Macon County, Ala., is the Susquehanna clay.

Montrose series.

The Montrose series so far as encountered occurs in the south-central part of Mississippi and extends into Alabama. The surface soils are gray and are underlain by heavy plastic yellow subsoils. The region where this occurs is locally known as "flatwoods" or "hog-wallow prairie." The area so far as seen is thickly timbered with post and scrub oaks and pine. The soils are derived from a deposit of heavy clay immediately overlying a soft chalky limestone.

Cotton is the principal crop on the sandy loam and yields from one-third to one-half bale per acre. Some corn is also produced, but after the first two crops the yields are low. Vegetables will do fairly well on this type, but it is not adapted to fruit. The type is valued at present for timber, which covers practically all of it. Frequently the drainage is inadequate, particularly on narrow strips near streams. On the better drained areas are found good growths of longleaf pine and some oak.

The Montrose clay is not a productive soil. It will produce one or two crops of corn, but the yield quickly declines. The soil is acid and much of it would need to be thoroughly drained before it could be brought under cultivation. The type was recognized in Jasper County, Miss., but such a small area was cultivated that no particular adaptation or yield can be given. The timber growth consists of scrawny post oak and black-jack oak, some other species of oak, and some shortleaf pine. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Montrose series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Montrose sandy loam	Mississippi	20,928
clay	do	43,840
Total		64,768

Myatt series.

The Myatt series occurs in seepy places around the heads of streams or in intermediate position between bottom lands and uplands. The soils are gray, while the subsoils are gray and yellow mottled with white.

The soils of the Myatt series are poorly drained and in part subject to overflow. They are still largely covered by forests. When cleared cotton and corn are the chief crops, the yield of cotton ranging from one-fourth bale to 1 bale per acre, with an average of about one-half bale. With proper drainage the lighter members would be well adapted to truck and small-fruit crops. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Myatt series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Myatt fine sand	Alabama	21,376
fine sandy loam	Alabama, Florida, Louisiana, Mississippi	61,440
clay loam	Mississippi	4,096
Total		86,912

Norfolk series.

The Norfolk series consists of light-colored sandy soils underlain by yellow or orange sand or sandy clay subsoils. Where the drainage is insufficient, the subsoil is often mottled. The members of this series are distinguished from those of the Portsmouth series by the lighter color of the surface material and from those of the Orangeburg series by the yellow color of the subsoils. The members of the Norfolk series, with few exceptions, are special purpose rather than general farming soils.

The series comprises the most important truck soils of the Coastal Plain, the different soils not only being specially adapted to special kinds of crops, but also having a wide general distribution from New York to Texas. Of this series the fine sand taken all in all is the leading soil for general trucking. In earliness it lies between the coarser soils on the one hand and the finer on the other. It is less leachy and droughty than the Norfolk sand or coarse sand, and is more easily kept in a productive state. Besides the lighter truck crops, it is a valuable soil in Florida for the production of a fine grade of Sumatra wrapper tobacco, and in North Carolina and Virginia for cigarette tobacco and peanuts. In Maryland it is the best soil for the French type of tobacco. In trucking areas large acreages are devoted to strawberry culture. In the sea islands of South Carolina it is the principal soil upon which the long-staple cotton industry has been developed.

Of the coarser types of the series the gravel and gravelly loam are not extensively developed and are not at present of much agricultural value. The coarse sand and coarse sandy loam are in the same category, but the Norfolk sand, which is a type of wide distribution, is an important soil because of its extreme earliness, and a consequent special use in the forcing of light truck crops for the very early market. It is a leachy and droughty soil and requires heavy manuring and fertilizing to produce profitable yields. Asparagus has proved a most profitable crop on this soil in North Carolina, and watermelons are grown with success in Georgia, extra early potatoes and lettuce in Virginia. These crops indicate special uses of the Norfolk sand, but there are many others that do equally as well in one or another part of its wide occurrence. A special adaptation in the sea islands is long-staple cotton.

The fine sandy loam is not so valuable for early truck as the fine sand, but is an excellent medium to late truck soil and in some sections it is known as "cabbage land." In North Carolina it is esteemed a better cigarette-tobacco soil than the sandy loam and fully equal to the fine sand. It is better for general farming than the lighter soils of the series, and is used extensively in the production of cotton, being the best of the Norfolk series of soils for growing this crop. In certain parts of Maryland it is a fine general purpose soil, giving good yields of wheat, corn, and hay in addition to heavy truck and fruit, principally peaches.

With a larger acreage than any of the other soils of the Norfolk series, the sandy loam is an important resource of the Coastal Plain. It is used for Irish and sweet potatoes, bright yellow tobacco, cotton, peanuts, and heavy truck crops and fruit. In Maryland some areas are considered the best general farming lands. This single type so far mapped comprises an area about half the size of Belgium.

The loam and silt loam are suited to diversified agriculture, the latter being rather the better soil. In New Jersey and Eastern Shore of Maryland good yields of wheat, corn, and hay are secured, and some dairying is practiced. The soil is used for the same general farm crops around Norfolk and in addition Irish and sweet potatoes are grown to some extent.

The clay is apparently most extensively developed in Alabama. In many cases it needs drainage, and with good cultivation produces good yields of cotton and corn. The table on page 106 shows the acreage of the several types so far encountered.

Area and distribution of the soils of the Norfolk series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Norfolk gravel	Maryland, New Jersey, New York, North Carolina.	138,670
gravelly loam	Alabama, Mississippi, Pennsylvania, Virginia	156,294
coarse sand	Alabama, Georgia, Maryland, Mississippi, New Jersey, New York, North Carolina, South Carolina.	206,450
coarse sandy loam	New York, Virginia	69,184
sand [a]	Alabama, Delaware, Florida, Georgia, Louisiana, Maryland, Mississippi, New Jersey, New York, North Carolina, South Carolina, Texas, Virginia.	2,074,712
fine sand [a]	Alabama, Florida, Georgia, Louisiana, Maryland, Mississippi, New Jersey, North Carolina, Pennsylvania, South Carolina Texas, Virginia.	1,319,164
sandy loam	Alabama, Florida, Georgia, Mississippi, New Jersey, North Carolina, South Carolina, Tennessee, Texas, Virginia.	1.454,898
fine sandy loam [b]	Alabama, Florida, Georgia, Indiana, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, South Carolina, Texas, Virginia.	3,118,980
very fine sandy loam	Florida	768
loam [c]	Alabama, Delaware, Florida, Kentucky, Maryland, Mississippi, New York, Pennsylvania, Virginia.	445,966
silt loam [d]	Alabama, Delaware, Maryland, New Jersey, North Carolina, Pennsylvania, South Carolina, Texas, Virginia.	518,532
clay loam	Virginia	1,856
clay	Alabama, Georgia, North Carolina	105 408
Total		9.612,882

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[a] The soils mapped as Norfolk sand in the Craven, N. C., Norfolk, Va., and Perry County, Ala., areas is Norfolk fine sand.

[b] Mapped as Miami fine sandy loam in the Boonville, Ind., area, Norfolk loam in Calvert, Prince George, and St. Mary counties, Md., and as Norfolk sandy loam in Fort Valley area, Georgia.

[c] Mapped in Calvert, Prince George, St. Mary, and Worcester counties, Md., and Perry County, Ala., as Sassafras sandy loam. Mapped in the Long Island, N. Y., area in part as Sassafras sandy loam and in part as Sassafras gravelly loam.

[d] Mapped in Calvert, Cecil, Harford, Prince George, St. Mary, and Worcester counties, Md., and Darlington, S. C., area as Sassafras loam and in the Kent County, Md., and Salem and Trenton, N. J., areas in part as Sassafras loam and Sassafras gravelly loam.

Oktibbeha series.

The Oktibbeha series occurs in the prairie belt of Alabama and Mississippi where it is known as "post-oak prairies." The soils are gray to yellowish brown and are underlain by the brown to brownish-yellow subsoils. This series is closely associated with the Houston soils and is derived from material immediately overlying the Selma chalk. The surface soil of the lighter textured members has been formed from a thin deposit of material probably belonging to the Columbia formation.

The Oktibbeha soils require careful handling, but with proper cultivation they produce good yields of the staple crops of the South. Cotton and corn are the crops on the fine sandy loam, virgin areas producing heavy yields. The silt loam needs drainage and under existing conditions it is considered a poor soil. On the other hand, the clay loam is one of the best cotton soils in Oktibbeha County, Miss., the only place where it has been mapped up to the present time. The clay is a difficult soil to handle and the farmers attach very little value to it. It is mainly used for pasture. Bermuda grass takes possession of the land when cleared. As a rule the soils of this series have not been greatly developed. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Oktibbeha series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Oktibbeha fine sandy loam	Mississippi	17,344
silt loam	do	13,824
clay loam	do	15,360
clay	do	25,920
Total		72,448

Orangeburg series.

The Orangeburg series is derived largely, but not entirely, from the Lafayette mantle of gravels, sands, and sandy clays. The surface soils are usually gray to brown in color, and are invariably underlain at a depth of 3 feet or less by a red or yellowish-red sandy clay. The prevailing red color of the subsoil is the characteristic feature distinguishing the Orangeburg series from the Norfolk series. The Orangeburg soils may be considered as the Coastal Plain equivalent of the Cecil series of the Piedmont Plateau.

The soils of the Orangeburg series are somewhat stronger than the corresponding types of the Norfolk series. They are used for about the same crops. The Orangeburg sand is a fine truck soil, and in Florida is used for growing Sumatra wrapper tobacco under shade. It has characteristics that suggest its adaptation to peach culture. The fine sand is an easily worked soil under a wide range of moisture conditions. It also has a wide crop adaptation, being used for truck, fruit, and the staples—corn and cotton. It is especially adapted to peaches and plums. The sandy loam is likewise adapted both to general farm crops and truck. In Orangeburg County, S. C., it is considered the best general farming soil, and is also used for bright-yellow tobacco, though some of the Norfolk soils give a better quality of leaf. In Florida, Alabama, and Texas it produces a high-grade cigar wrapper and filler leaf. The coarse sandy loam has a rather low agricultural value. With the most extensive development of any of the soils of this series, the fine sandy loam is a very important Coastal Plain soil. Cotton, corn, tobacco (both the bright-yellow cigarette in South Carolina and the Cuban filler cigar types in Alabama and Texas), fruit, and truck are grown. In the Fort Valley section of Georgia it is the principal peach soil, and in east Texas this crop is also an important one. Strawberries and other small fruits thrive. Cotton is the chief crop upon the Orangeburg clay, which is typically the best general farming soil of the series. Grain and forage crops do well upon it and stock raising or dairying are industries that might be introduced. This clay often has a veneering of sandy loam, and in such cases is used to advantage for truck and small fruit. The two types, gravelly sandy loam and loam, have so far been found in limited areas. The latter is an excellent soil for cotton and the staple general farming crops.

The acreage of the different types so far encountered is as follows:

Area and distribution of the soils of the Orangeburg series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Orangeburg coarse sandy loam	South Carolina	8,256
gravelly sandy loam	Texas	5,376
sand[a]	Alabama, Florida, Georgia, Louisiana, Mississippi, South Carolina, Texas.	253,760
fine sand	Alabama, Georgia, Louisiana, Mississippi, Texas.	391,104
sandy loam[b]	Alabama, Florida, Louisiana, Mississippi, South Carolina, Texas.	316,224
fine sandy loam[c]	Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, Texas.	2,034,816
loam	Florida, Mississippi	3,264
clay	Alabama, Georgia, Mississippi, South Carolina, Texas.	473,664
Total		3,486,464

[a] Mapped in the Darlington, S. C., area as Orangeburg sandy loam.
[b] Mapped in the Darlington, S. C., area as Orangeburg loam.
[c] Mapped in Fort Valley, Ga., Gadsden County, Fla., and Perry County, Ala., areas as Orangeburg sandy loam.

Portsmouth series.

The Portsmouth series is characterized by dark-gray to black surface soils, underlain by yellow, gray, or mottled yellow and gray subsoils. The dark color of the soils is due to an accumulation of organic matter during an earlier or existing swampy condition. This series may be considered as intermediate between the light-colored Norfolk soils on the one hand and the Peat and Swamp areas on the other. The members of the series occupy depressed areas, or areas so flat that the water table is at or near the surface, except where artificial drainage has been resorted to.

Notwithstanding their naturally poorly drained condition, the soils of this series are in most instances easily reclaimed by ditching, and when brought into proper condition are highly productive for both the general farm and special crops. The sandy members of the series are very desirable for strawberries, especially for late varieties. They are also well suited to truck crops, such as cabbage, kale, lettuce, and root crops, and could be used to advantage for celery, onions, and other crops that thrive in soils of high organic matter content. In Duplin County, N. C., the sand and fine sandy loam have been found particularly adapted to the growing of bulbs, large yields of tuberoses, dahlias, and cannas being secured. The heavier members are used chiefly for corn, small grain, and grass, though they are also used in places for celery, onions, and cabbage. A relatively small proportion of this series has been developed and but little of this has been highly developed.

The acreage of the types so far encountered is shown in the following table:

Area and distribution of the soils of the Portsmouth series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Portsmouth sand	Delaware, Florida, Georgia, Maryland, North Carolina, Virginia.	136,320
fine sand	Florida, Georgia, North Carolina	328,000
sandy loam	Delaware, Florida, Maryland, North Carolina, South Carolina, Texas, Virginia.	667,108
fine sandy loam	Florida, Georgia, North Carolina, South Carolina, Virginia.	301,476
loam	Maryland, Mississippi, North Carolina	111,424
silt loam[a]	Kentucky, North Carolina, Virginia	182,656
clay loam	Virginia	2,176
Total		1,729,160

[a] The Portsmouth silt loam in the Chester County, Pa., report is Elkton silt loam, and in the Norfolk, Va., area was mapped as the Leonardtown loam and Leonardtown gravelly loam.

Sassafras series.

The soils of the Sassafras series consist of yellowish-brown surface soils underlain by slightly reddish-yellow or light orange subsoils. At a depth varying from 2½ to 5 feet occur beds of gravel or sand. The soils of this series are distinguished from the Norfolk by the brown surface soils, slightly redder subsoils, the presence of the gravel beds in the lower subsoil, the adhesion of finer particles to the sands, and a higher agricultural value. They have been formed from marine and estuary deposits composed of material derived from the Piedmont Plateau and limestone valleys mingled with glacial material brought down by the larger rivers. They occur as distinct terraces from 10 to 250 feet above sea level in the Coastal Plains around Chesapeake Bay and northward. This series includes some of the most productive soils of the Atlantic seaboard.

The sand and loamy sand are light, well-drained, naturally warm, early soils especially adapted to truck crops like garden peas, asparagus, early Irish potatoes, strawberries, and dewberries. The sandy loam is widely distributed and is a good soil for general farming. It is considered the best tomato soil of the Eastern Shore. Strawberries, potatoes, asparagus, peaches, pears, dewberries, and other small fruit make excellent yields. The crop adaptations and agricultural value of the fine sandy loam are nearly the same as for the sandy loam. It is, however, better suited to grass than the latter type. The loam is probably the best all-round general farming soil of the north pasture land. In the Laredo area, where it was first recognized, none of the soil is under cultivation, being exclusively used for grazing cattle. The gravelly sandy loam is not well adapted to cultivated crops, as both irrigation and cultivation are difficult. It is naturally better adapted to fruit growing. The type has only been found in the Laredo area, Texas, where none of it is under cultivation, being used exclusively as pasture land. The acreage of the different types so far encountered is as follows:

Area and distribution of the soils of the Webb series.

Soil name.	State in which each type has been found.	Total area.
		Acres.
Webb gravelly sandy loam	Texas	53,760
fine sand	do	3,136
fine sandy loam	do	110,528
loam	do	17,088
Total		184,512

Wickham series.

The soils of this series occur as river terraces in the higher part of the Coastal Plain, near its contact with the Piedmont Plateau. They are characterized by reddish or reddish-brown surface soils containing a higher percentage of organic matter than the Norfolk series, and usually overlie reddish, micaceous heavy sandy loam or loam subsoils which become coarser, looser, and more incoherent at about 30 inches. The soils generally have a level or gently undulating surface, are fairly well drained, and possess a retentive subsoil.

The Wickham soils are for the most part productive, having the advantage of alluvial deposits without the disadvantages of overflow and poor drainage. They are, however, of limited occurrence, having been mapped so far in only two areas, both in Virginia. They are, at present, used for general farming. The heavier soils produce large yields of wheat, oats, corn, and hay. The acreage of the different types so far encountered is as follows:

Area and distribution of the soils of the Wickham series.

Soil name.	State in which each type has been found.	Total area.
		Acres.
Wickham sand	Virginia	4,416
sandy loam	do	5,120
loam	do	5,952
clay loam	do	2,176
Total		17,664

Wilson series.

The Wilson series, like the Crockett series, occurs as prairies scattered through the timbered region of Texas. The surface soils are very much like the Crockett soils, varying from gray to almost black. The subsoils are mottled gray and drab. This series forms a gradation between the Houston and Lufkin series.

The clay loam is a strong soil, devoted to cotton, corn, oats, and sorghum. The fine sandy loam and loam are droughty soils. Cotton seems to be their best crop. The acreage of the different types so far encountered is as follows:

Area and distribution of the soils of the Wilson series.

Soil name.	State in which each type has been found.	Total area.
		Acres.
Wilson fine sandy loam	Texas	4,288
loam	do	98,880
clay loam	do	71,872
Total		175,040

Miscellaneous soils of the Atlantic and Gulf Coastal Plains.

Important areas of the Acadia silt loam have been mapped in Louisiana and in Arkansas. In the former State very little of the soil is at present under cultivation, but in Arkansas it is used extensively in the production of cotton, corn, and oats. Apples, peaches, pears, plums, and small fruits are produced for home use, and could be grown more extensively. Cowpeas are an important crop and are cut for hay.

Small areas of a soil called Alloway clay have been mapped in New Jersey. It is sedimentary in origin and occupies both rolling uplands and stream bottoms. Fine apples are produced upon it, and grass and wheat thrive.

A limited area of Amite loam has been surveyed. It occurs in Louisiana and is of alluvial origin, though occupying higher flood plains. Corn produces from 30 to 40 bushels per acre and cotton does well. The soil is adapted also to sugar cane and some truck crops.

The Amite sandy loam, a sedimentary second-bottom soil found so far only in Louisiana, is a valuable soil with wide crop possibilities. The determined or suggested adaptations include corn, cotton, oats, sweet and Irish potatoes, sugar cane, and truck.

The Caddo fine sandy loam in point of extent is an important soil of Caddo Parish, La. It is largely occupied by forest and needs drainage. Though used mainly for cotton and corn, of which the yields are large, the soil is probably even better adapted to plants requiring a moist soil, for instance, sugar cane, rice, some truck crops, and strawberries.

Of occurrence only in Louisiana, where about 20 square miles of it have been mapped, the Calcasieu fine sand is a sedimentary soil. It occurs in two phases, a fine sandy loam and fine sand, both of which are adapted to truck and fruit.

The Calcasieu loam, a sedimentary soil of Louisiana, is found in depressions and is poorly drained. It has been found to be an excellent soil for rice, an impervious clay subsoil preventing the waste of water during the flooding period.

A relatively small area of Calcasieu fine sandy loam has been found in Texas and Louisiana. It is a good truck soil and is also adapted to pears and berries.

The Chesterfield sandy loam occupies the greater part of Chesterfield County, Va. It is a soil of uncertain derivation, being partly residual and partly sedimentary. It varies in productiveness, but for the most part gives moderate yields. Wheat, corn, oats, and shipping tobacco are the crops grown. The gravelly soil of this name is little used for cultivation, owing to the difficulties of handling. The least stony areas give fair yields.

Among the most productive soils of New Jersey and Coastal Plain Maryland may be placed the Collington sandy loam. Over 110,000 acres of this soil have been mapped in the two States named. The soil is derived through weathering from a green glauconite sand, the pure greensand being found at an average depth of 30 to 40 inches. The areas of this soil are used for small fruit, nursery stock, truck, and tobacco.

The Crowley silt loam is one of the most extensively developed soils of the southern coastal plain region. It occupies level or slightly rolling prairies and in south Louisiana is considered one of the very best soils for rice growing. Well-drained areas are adapted to cotton and oats.

The Durant sand and the Durant fine sandy loam were mapped in Indian Territory. The former is a light sandy loam of low value for general farm crops. Cotton and corn are the only crops grown on the limited areas under cultivation. The fine sandy loam occupies a rolling plain, is well drained, and easily cultivated. Derived from sandstone with interstratified limestone deposits, the soil is calcareous and above the average in fertility. It is for the most part treeless and was one of the first soils to be settled. While not as productive as contiguous areas of Houston black clay, the better phase of the soil is highly esteemed. Cotton, corn, and oats are the important crops.

The Gainesville sand, of which one comparatively small area has been found in Florida, is well drained and inclined to be droughty. The sand is, however, loamy and underlain by clay at about 3 feet, which has a tendency to maintain a moisture supply in all but extremely dry periods. Sea Island cotton is the principal crop, the soil being especially fitted for the production of this valuable variety. Corn, oats, and peanuts are also successfully produced and some areas are used for general farming and the raising of cattle and hogs.

A better general farming soil than the last described, a greater proportion of the Glenn loam is under cultivation, though there is still much of it in forest. Cotton, corn, and oats are the important crops. Apple trees make a thrifty growth and produce a fruit of good quality.

The Glenn sandy loam is for the most part in forest of oak, with a scattering of pine. Cotton and corn are leading crops, the yields being light and uncertain. Peaches do fairly well. Potatoes, peanuts, and some of the truck crops would give better results than the crops grown at present.

Only one small area of the Greenville fine sandy loam has been mapped to the present time. It is closely related to the Orangeburg fine sandy loam and differs from it in having a red surface soil. It is held to be somewhat more productive than the Orangeburg soil. Being found in Alabama, it is used chiefly for cotton and corn.

The Greenville gravelly sandy loam is a fair type for the production of cotton and corn. It is recognized as very well adapted to peaches, small fruits, and vegetables, and in the early days a very good grade of tobacco was grown for home use.

The Greenville loam is a strong productive soil, especially well adapted to growing cotton, corn, and oats. It is not so well adapted to fruit and vegetables. It maintains improvement well and is not easily exhausted under ordinary treatment. It occurs in small areas.

The Hammond silt loam is a level, poorly drained soil of southeastern Louisiana. It is naturally unproductive, being deficient in organic matter. Sugar cane, oats, small truck, and crab-grass hay are the crops succeeding best on this soil.

The greater part of the Harley sandy loam is still in forest, but small areas planted to corn and cotton give good yields. The soil is better adapted to potatoes, fruit, and truck crops. It resembles some of the typical-peach soils of the country and the few trees seen upon it were in a thrifty condition.

The Hempstead loam is a friable soil containing some gravel, with a level surface and good drainage. It produces good crops of corn, potatoes, tomatoes, cabbage, rye, and grass, and is also a fair soil for late truck. This soil has been encountered only in Long Island.

The Lacasine clay loam is a heavy, intractable soil found in depressions in swamps. It has little present agricultural value.

The Lake Charles fine sandy loam, limited to Louisiana and Texas, is a soil of heavy fine sandy loam texture underlain by still heavier material. The surface is marked by sand mounds and the elevation is relatively high, so that drainage is fairly good. It is adapted to crops requiring a moderately light soil and a plentiful moisture supply.

A small area of the Lake Charles loam was mapped in Louisiana. Though heavy and difficult to till, it makes excellent rice land.

The Lamar loam is found in Texas. Little of it is under cultivation, as the surface is rough and eroded and washing is severe when the soil is plowed and allowed to lie unprotected. Its main value is as pasture land.

Another of the miscellaneous soils of Louisiana is the Landry silt loam. This type has a rolling surface and is not irrigable, which prevents its utilization for rice growing. It is a fairly good cotton soil.

The Leonardtown loam is a valuable upland soil of Maryland and Virginia. The surface is slightly rolling, the drainage in most areas is good, and altogether the land is well suited to general farming. The soil has a special value in the production of wheat and grass.

The Leon fine sand, like the sand, is poorly drained and at present valued only for its covering of longleaf pine. Consisting of a sand resting on a sandy subsoil, it would doubtless prove droughty if too thoroughly drained. With care to secure the right moisture conditions, it could be used for certain lines of agriculture, though many years will elapse before reclamation will be economical.

No areas of the Leon sand are under cultivation, the type being poorly drained. It supports a good growth of longleaf pine, which is at present its sole value.

The Mobile clay is a grain and grass soil of limited area. It is poorly drained and of little agricultural value.

The Monroe silt loam, mapped only in Louisiana, is mainly in forest of oak and pine. On the few areas where cultivation has been attempted the crops, cotton and corn, have given small yields.

The Morse clay is another soil of slight extent and little agricultural importance. Where irrigable rice can be grown and well-drained areas are adapted to corn and cotton.

Muck and Peat: These soils are composed largely of organic matter in various conditions of decay, the Muck representing an advanced stage of change in Peat areas. Of relatively limited extent, and poorly drained, these soils are highly valued for their adaptation to special crops, such as celery, onions, peppermint, and cabbage.

Derived from limestone, the San Antonio clay loam, a type found only in western Texas, is a very productive soil. Under irrigation it is an excellent fruit soil. It is also adapted to cotton, corn, sorghum, and hay. Alfalfa gives fair returns.

Sandhill, Dunesand, and Coastal beach consist of deep sands of little or no agricultural value.

Swamp, Tidal swamp and marsh: Under these heads are grouped areas covered with water the greater part of the year and unfit for agriculture except where drained and protected from tidal or fluvial overflow. When reclaimed much of this land will become very productive.

The Travis gravelly loam, found in Texas, is composed of old alluvium forming terraces along streams. The high location, together with the large quantity of gravel in the soil and subsoil, renders the type droughty, and it is valued more for its forest growth than for farming. On level areas cotton, corn, and oats give light yields. The soil seems better adapted to tree fruits and melons than for general farm crops.

The Warsaw sandy loam is a well-drained second-terrace soil found in Alabama. This is a productive type well suited to general farm crops and to certain truck crops. On the more elevated areas small fruits and peaches do well.

The acreage of the miscellaneous types described above is as follows:

Area and distribution of the miscellaneous soils of the Atlantic and Gulf Coastal Plains.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Acadia silt loam	Arkansas, Louisiana	225,792
Alloway clay	New Jersey	22,484
Amite loam	Louisiana	16,320
Amite sandy loam	do	7,232
Caddo fine sandy loam	Louisiana, Texas	151,680
Calcasieu fine sand	Louisiana	13,970
Calcasieu loam	do	51,280
Calcasieu fine sandy loam	Louisiana, Texas	28,540
Chesterfield gravelly sandy loam	Virginia	34,304
Chesterfield sandy loam	do	95,680
Collington sandy loam	Maryland, New Jersey	110,886
Crowley silt loam[a]	Arkansas, Louisiana	477,120
Durant fine sandy loam	Oklahoma	25,728
Durant sand	do	4,288
Gainesville sand	Florida	7,744
Glenn loam	Alabama	85,584
Glenn sandy loam	do	73,600
Greenville gravelly sandy loam	Louisiana	10,752
Greenville fine sandy loam	Alabama	9,152
Greenville loam	Louisiana	2,048
Hammond silt loam	do	70,976
Harley sandy loam	Oklahoma	8,832
Hempstead loam	New York	53,824
Lacasine clay loam	Louisiana	3,470
Lake Charles fine sandy loam	Louisiana, Texas	182,708
Lake Charles loam	Louisiana	6,378
Lamar loam	Texas	5,696
Landry silt loam	Louisiana	37,696
Leonardtown loam[b]	Kentucky, Maryland, Virginia	196,834
Leon fine sand	Florida	17,728

[a] Mapped in part as Miami clay loam and in part as Elmira silt loam in the Stuttgart area, Arkansas.

[b] The Leonardtown loam and Leonardtown gravelly loam in the Norfolk, Va., report are the Portsmouth silt loam.

Area and distribution of the miscellaneous soils of the Atlantic and Gulf Coastal Plains—Continued.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Leon sand	Florida	61,376
Mobile clay	Alabama	896
Monroe silt loam	Louisiana, Mississippi	300,992
Morse clay	Arkansas, Louisiana	7,424
Muck and Peat	Florida, Louisiana	65,568
San Antonio clay loam	Texas	28,608
Sandhill, Dunesand and Coastal beach.	Delaware, Florida, Georgia, Maryland, New York, North Carolina, South Carolina, Texas, Virginia.	182,664
Swamp, Tidal swamp and marsh	Delaware, Florida, Georgia, Louisiana, Maryland, New York, North Carolina, South Carolina, Texas, Virginia.	982,218
Travis gravelly loam	Texas	25,728
Warsaw sandy loam	Alabama	33,408
Total		3,627,198

RIVER FLOOD PLAINS.

An extensive and characteristic group of soils, usually known as "bottom lands," is found in the flood plains of numerous rivers and streams of the United States. The largest development of this group occurs along the Mississippi River, where the bottoms are often many miles in width.

The soils have been formed by deposition from stream waters during periods of overflow. The texture of the material depends upon the velocity of the current at the time of the deposition. Where the current is very rapid, large stones and bowlders are borne along and beds of gravel and sand are formed. Along the swift-flowing streams the texture of the soil changes often within short distances, but in wide bottoms large areas of very uniform soils are often formed. The soil material has usually been derived from various kinds of rocks, but in some instances is closely related to the surrounding geological formation. The red soils along the Red and other rivers in the Southwest have been formed by the reworking of the Permian Red Beds. In general, the soils along the streams which flow through the prairie region have a darker color than those along the streams which run only through the timbered sections of the country.

The difference in the origin, drainage, color, and organic matter content has given rise to several series of alluvial soils in the humid portion of the United States.

The aggregate area of the soils surveyed in this province is 8,061,453 acres.

Congaree series.

The soils of the Congaree series are brown to reddish-brown in color, and are composed of material which has been washed from the red Cecil soils of the Piedmont Plateau. As the latter series is derived from crystalline rocks, the Congaree soils usually contain considerable amounts of mica. While they are found along streams in the Piedmont Plateau, they also occur along streams issuing from this region.

The Congaree soils, which occur in small, narrow areas along the streams in all parts of the Piedmont section of the South, are highly valued because of the fine crops of corn that can be harvested year after year upon them. Being subject to overflow, with annual deposition of material washed from fertile upland soil, their productiveness is kept at a high point, and they are so situated that even in dry years the moisture conditions are very favorable. Sorghum and sugar cane are two other crops that produce well. Cotton is apt to run to weed and to mature late, causing a loss of a part of the bolls through frost. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Congaree series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Congaree fine sandy loam	South Carolina	23,360
loam	Alabama, Mississippi, South Carolina, Virginia	140,416
clay[a]	Alabama, South Carolina	19,456
Total		183,232

[a] Mapped as Ocklocknee clay in Macon County, Ala.

Huntington series.

Throughout the area of the Allegheny Plateau there are found along the streams areas or strips of overflow bottom lands, varying in width from a few yards to 3 or 4 miles. The soils are formed by the reworking of materials derived from sandstones, shales, and limestones. Those having a dark-brown to yellow-brown color have been included in the Huntington series.

Somewhat more extensively developed than the Wheeling soils, the Huntington soils, with the exception of the gravelly loam, are very valuable for both general farm crops and truck. The loam is used largely for trucking; the silt loam for corn, potatoes, hay, and truck, with some areas in sorghum and alfalfa. The fine sandy loam is apportioned between the general farm crops mentioned and garden vegetables. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Huntington series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Huntington gravelly loam	Tennessee	14,464
fine sandy loam	Indiana, Pennsylvania, West Virginia	20,864
loam	Indiana, New York, Pennsylvania, Tennessee, Virginia, West Virginia.	101,824
silt loam	Alabama, Indiana, New York, Ohio, Tennessee, Virginia.	121,844
Total		258,496

Miller series.

The soils of the Miller series are distinguished from those of the Wabash and Waverly series by their reddish color. They occur along the Red and other rivers that flow through the Permian Red Beds and represent this material reworked by streams. As these streams flow away from the areas covered by the Red Beds, material from the surrounding country is added, so the soils gradually lose their red color and change to the Wabash or Waverly series.

Soils of the Miller series are among the most productive alluvial soils of the United States. The Miller fine sand gives moderate yields of cotton and corn, and higher lying areas seem adapted to fruit, especially peaches. Vegetables also do well. The fine sandy loam, a more extensive member of the series, gives better yields of cotton and corn, and is also well adapted to truck and fruit, peaches, plums, and pears being grown to considerable extent in parts of Texas. It is also an excellent soil for alfalfa, the acreage of which has been rapidly extended in recent years. Vegetables may be grown with profit, and in some cases irrigation is practiced, the water being secured from artesian wells. The silt loam has about the same extent as the fine sand. It is used for about the same crops as the fine sandy loam and clay, i. e., cotton, corn, sugar cane, and alfalfa. The clay is the most extensive and strongest soil of the series. Surpassed by few soils in the production of cotton and alfalfa, it is no less valuable in the growing of sugar cane. The Miller soils from their origin and the relatively circumscribed area of the formation from which they are derived are not an extensive series. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Miller series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Miller fine sand	Arkansas, Louisiana, Texas	66,944
fine sandy loam	Arkansas, Louisiana, Oklahoma, Texas	177,216
loam	Oklahoma	37,184
silt loam [a]	Louisiana, Texas	54,208
clay [b]	Arkansas, Louisiana, Oklahoma, Texas	260,352
Total		595,904

[a] Mapped as Vernon silt loam in Vernon area, Texas.
[b] Mapped as Sharkey clay in Miller County area, Arkansas.

Ocklocknee series.

The Ocklocknee series occurs as the better drained bottom lands in the Coastal Plains region, principally of Georgia, Alabama, and Mississippi. It is formed by the reworking of noncalcareous unconsolidated deposits. The soils are gray to yellowish-brown and do not show a large amount of mottling.

The soils when well drained are among the most productive soils in the Coastal Plains. Very little of the clay is as yet cultivated, although it is capable of producing large yields of cotton and corn. Some excellent pasture is found, but the soil will not be used much for agricultural purposes until the streams are put under better control and the drainage improved. The loam is at present valued largely for its timber. It would require a large expenditure to put it into cultivation and prevent the injury to crops by inundation. When well drained it will produce good crops of both corn and cotton. The fine sandy loam usually lies higher above the stream than the heavier soil, but much of the type requires drainage. When this is done it proves a good cotton and corn soil. The sand is very limited in extent and is of little importance agriculturally. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Ocklocknee series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Ocklocknee sand	Alabama	960
fine sandy loam	do	28,544
loam	Mississippi	103,360
clay loam	do	13,632
clay[a]	Alabama, Florida, Georgia, Mississippi	89,920
Total		236,416

[a] The soil mapped as Ocklocknee clay in Macon County, Ala., is Congaree clay.

Wabash series.

The Wabash series comprises the most important of the alluvial types of soil. It embraces those soils having a dark-brown to black color and a large percentage of organic matter. These soils are typical of the Mississippi River, but there is no sharp distinction between them and other bottom soils found along the rivers of the Middle West.

The Wabash soils are among the strongest and most productive types of the country.

The most extensive type of the series is the silt loam, by far the greater part of which is found north of the southern tier of States, and therefore cotton is not as important a crop as corn, grass, and small grains, of which fair to large yields are secured, depending upon the condition of drainage. The next soil in point of area is the Wabash clay. In the Southern States this is considered the best cotton soil, producing on the average over a bale of lint to the acre. Farther north it gives large yields of corn. A small area of the heavy clay has been found in Texas, where it gives heavy yields of cotton, corn, oats, and forage crops. The Wabash loam is the third soil in area; occurring to the north of the cotton sections it is used chiefly for corn, to which it is well adapted. It can be used to advantage in the production of canning crops, such as sugar corn, tomatoes, green peas, and beans. The fine sandy loam is of limited extent. Some areas produce heavy yields of wheat, oats, corn, while others are better suited to melons, sugar beets, Irish potatoes, and alfalfa. The principal crop on the sandy loam is corn. It is also suited to truck crops. The heavier silt loam and clay loam are both valuable soils, though as yet only small areas have been encountered in the soil survey. Heavy yields of grass, corn, alfalfa, Kafir corn, sorghum, and moderate yields of small grains are obtained. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Wabash series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Wabash fine sand	Arkansas, Oklahoma	19,008
sandy loam [a]	Indiana, Ohio	6,624
fine sandy loam [b]	Arkansas, Indiana, Minnesota, Nebraska, Oklahoma.	71,872
loam [c]	Arkansas, Illinois, Michigan, Minnesota, Missouri, New York, North Dakota, Ohio, Wisconsin.	264,176
silt loam [d]	Alabama, Arkansas, Illinois, Indiana, Iowa, Kansas, Kentucky, Minnesota, Missouri, Nebraska, Oklahoma, Tennessee.	854,366
silt clay	Kansas, Oklahoma	9,984
clay loam	Arkansas	11,584
clay [e]	Alabama, Arkansas, Illinois, Kansas, Louisiana, Mississippi, Missouri, Nebraska, North Dakota, Ohio, Oklahoma, Texas.	610,635
heavy clay	Texas	13,248
Total		1,861,497

[a] Mapped as Miami sandy loam in the Montgomery County area, Ohio.

[b] Mapped as Miami sandy loam in Posey County, Ind.

[c] Mapped as Miami loam in Auburn, Lyons, and Syracuse areas, New York; Columbus, Coshocton, and Montgomery counties, and Toledo and Westerville areas, Ohio; Fargo and Grand Forks areas, North Dakota; Marshall area, Minnesota; Pontiac area, Michigan; and Viroqua area, Wisconsin, and as Lintonia loam in Tazewell County, Ill.

[d] Mapped as Lintonia loam in the Dubuque area, Iowa, and as Waverly silt loam in Posey County, Ind., and Union County, Ky.

[e] Mapped as Yazoo clay and Sharkey clay in Allen County, Kans., and as Sharkey clay in Parsons area, Kansas.

Waverly series.

The Waverly series is characterized by light-colored surface soils, with drab, gray, and mottled yellow or white subsoils. The soils of this series occur almost entirely along the streams east of the Mississippi River.

Though occupying the same position as the Miller and Wabash series, the Waverly soils are decidedly less productive. They range from fine sandy loam to clay, and in general are used for corn and cotton. The fine sandy loam is adapted to corn, melons, early vegetables, and alfalfa, while wheat, oats, and potatoes are successfully grown. The loam is, according to location, adapted to cotton and corn, or to corn, wheat, and forage crops. Overflows render the successful use of this soil problematical in certain areas. Corn is the principal crop on the silt loam, and in the South cotton is also an important crop; the yields are good. The soil has a marked adaptability for sugar cane, giving large yields of a superior quality of sirup. Cabbage and peas are grown, and other truck crops could be produced on a commercial scale. The clay loam seems best adapted to clover, timothy, and redtop. Export tobacco, wheat, and corn are other products of this soil, the yields depending on the character of drainage and cultivation. On well-drained areas of the clay, where protected from overflows, corn, wheat, grasses, oats, and tobacco yield well. The heavier members of this series have not been developed to so great an extent as the corresponding types of the Wabash series. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Waverly series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Waverly fine sandy loam[a]	Illinois, Indiana, Kentucky, Mississippi	18,176
loam[b]	Alabama, Indiana, Mississippi, Tennessee	182,016
silt loam[c]	Arkansas, Illinois, Indiana, Kentucky, Mississippi, Missouri, Tennessee.	393,472
clay loam[d]	Illinois, Indiana, Missouri	68,224
clay[e]	Alabama, Arkansas, Indiana, Kentucky, Mississippi, Ohio.	220,352
Total		882,240

[a] Mapped as Miami fine sandy loam in Posey County, Ind., and Union County, Ky., and as Yazoo sandy loam in Clay County, Ill.

[b] Mapped as Yazoo loam in Posey County, Ind.

[c] The soil mapped as Waverly silt loam in Posey County, Ind., and Union County, Ky., is Wabash silt loam.

[d] Mapped as Guthrie clay in Posey County, Ind.

[e] Mapped as Yazoo clay and Sharkey clay in Union County, Ky.

Wheeling series.

About the close of the Glacial epoch there was formed along the Ohio and other rivers issuing from ice-covered regions a series of gravel terraces. The terrace soils which have been formed by streams issuing from areas where the upland soils are composed of ground-up sandstone and shales have been included in the Wheeling series. The gravel is composed largely of sandstone and shale, although granite and other crystalline rocks are also present. Shale being a rather soft rock, the percentage generally decreases as the distance from the source of the material decreases. The soils are brown to yellow brown in color and are underlain by gravel, usually within 3 feet of the surface.

While of limited extent the Wheeling soils are important in relation to other soils of the region where they occur. The gravelly loam—the most extensive soil—has a wide adaptation, being suited to the production of the general farm crops, truck, and fruit. The sandy loam is especially adapted to apples, and is nearly all occupied by bearing orchards. The silt loam is a well-drained terrace soil. and is valued as a potato soil, though producing fine crops of tomatoes, corn, wheat, and hay. The fine sandy loam is best adapted to melons and strawberries. Other small fruits do well, while the staples—potatoes, corn, wheat, and hay—are grown with good results. About the same crops are produced on the fine sand with marked results with melons and tomatoes.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Wheeling series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Wheeling gravelly loam	Ohio, West Virginia	11,392
fine sand	Ohio	640
sandy loam	West Virginia	768
fine sandy loam	Ohio	1,984
silt loam	Ohio, West Virginia	5,248
Total		20,032

Miscellaneous soils of the river flood plains.

In this province, where the soils are now forming or have recently formed, a good many soils have been encountered which have no such common properties as to suggest definite relationships that would justify their being put into any one of the established series, but it is not unlikely that with further work in the extension of the surveys new series may be established and some of these miscellaneous soils be brought into them. The various uses to which these miscellaneous soils are now being put are briefly shown in the following paragraphs:

On the Austin fine sandy loam the corps grown are cotton, corn, fruit, and some vegetables. Considerable sorghum fodder is produced, and under favorable conditions it is thought alfalfa would make abundant crops.

The Biscoe silt loam in Arkansas is well adapted to cotton and corn, which are the principal crops grown on it. It would probably do well if planted to alfalfa, and with proper cultural methods prove an excellent truck soil.

The Blanco loam occurs in such small areas that it is of minor importance, but is productive, especially when irrigated. It makes good yields of corn, cotton, Irish potatoes, and sweet potatoes. It is well suited to vegetables. Large yields of alfalfa are secured when irrigated.

Only limited areas of the Brennan fine sandy loam are cultivated. Favorable seasons tend to make fair yields of corn, cowpeas, and sorghum on this soil. It is chiefly valued as pasture land.

The Calhoun clay is poorly drained, but if drained should prove a good soil for cotton.

The Cameron clay was formerly used for rice culture in Texas, but accumulations of salts have discouraged the cultivation of this crop. Where well drained good yields of the general farm crops are secured.

Little of the Carrington clay loam is under cultivation. It is a difficult soil to till, but should produce good yields of wheat.

The Catalpa silt loam requires drainage, but when reclaimed is a very valuable general farming soil.

The Chattooga loam is a productive soil for corn.

In Arkansas, where it occurs, the Collins silt loam produces cotton, corn, and potatoes.

The Franklin loam is little cultivated. It produces some cotton and corn.

The Griffen clay is largely covered with forest. Corn is the chief crop on cultivated areas, and some wheat and oats are grown.

The Jackson loam is used for wheat and corn. It is adapted to light farm crops and truck, wrapper tobacco, and peaches.

The Lintonia loam is a good cotton soil and well adapted to market gardening and fruit culture. In northern areas it produces corn, wheat, oats, and potatoes.

The Lomalto clay is affected with alkali and the opportunity for drainage is poor, so that little agricultural value attaches to this soil.

Meadow consists of low-lying, flat, and poorly drained land of variable texture. Frequently of some value for grass and pasturage, and in the South for corn after subsidence of floods. Much more of it can be reclaimed by simple methods of drainage, and when this is done excellent results can be secured from a variety of crops.

Muck and Peat are soils composed largely of organic matter in various conditions of decay, the Muck representing an advanced stage of change in Peat areas. Of relatively limited extent, and poorly drained, these soils are highly valued for their adaptation to special crops, such as celery, onions, peppermint, and cabbage.

The Neosho silt loam is best adapted to wheat and grass, but in normal seasons corn and oats do well. The soil is in need of drainage.

The Neuse clay is poorly adapted for agriculture on account of its close, sticky nature and poor drainage, but when well drained is a good cotton soil.

The Point Isabel clay is of little agricultural value.

The Rio Grande silty clay, a semiarid type of soil, is largely covered with native vegetation of water-loving species. Without irrigation a few areas produce corn and cotton.

The Sanders silt loam is subject to overflow, but under favorable conditions makes good crops of corn, cotton, and Johnson and Bermuda grasses. Heavy yields of sirup are secured.

The Sanders loam is a very good corn soil, but not so well suited to the production of cotton. It generally needs drainage.

When well drained the Sarpy clay loam makes excellent corn land. It is used to some extent for alfalfa, of which excellent yields are secured.

The Sharkey clay lies along streams in the South, where it is locally known as "Buckshot land." When diked and well drained it is a strong soil, suited to corn, sugar cane, and cotton.

Swamp and Marsh comprise areas covered with water the greater part of the year and unfit for agriculture except where drained and protected from tidal or fluvial overflow. When reclaimed much of this land will become very productive.

The principal crops grown on the Teller fine sandy loam are cotton and corn. The Teller fine sand, in addition to cotton and corn, of which very fair yields are obtained, is well adapted to potatoes, melons, and other truck crops and to fruits.

The Toxaway fine sandy loam and loam are among the most productive soils of the mountain valleys where they occur. The loam is used for corn, hay, and wheat. The fine sandy loam, while used for the same crops, is really better suited to the production of vegetables, melons, and other truck crops.

The Tyler silt loam is poorly drained, crawfishy land. It is not well adapted to wheat, but fair yields of oats and corn are secured. It is mainly used for grazing or pasture lands.

The Yazoo sandy loam occupies low, flat ridges forming front lands near stream courses. The chief product is cotton, but the soil is suited to truck and market garden crops. Corn and truck do well in the more northern area.

The Yazoo loam is used chiefly for cotton, but it is by nature better adapted to truck and market garden crops. The loam is a strong cotton soil. In northern areas it is adapted to corn and wheat.

The acreage of the types so far encountered is given in the following table:

Area and distribution of miscellaneous soils of the river flood plains.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Austin fine sandy loam	Texas	32,576
Biscoe silt loam	Arkansas	12,992
Blanco loam	Texas	5,376
Brennan fine sandy loam	do	11,584
Calhoun clay	Arkansas	12,672
Cameron clay	Texas	27,072
Carrington clay loam	North Dakota	6,272
Catalpa silt loam	Mississippi	5,056
Chattooga loam	Alabama	5,696
Collins silt loam	Arkansas	8,576
Franklin loam	Texas	1,280
Griffin clay	Indiana	1,600
Jackson loam	Missouri	2,304

Area and distribution of miscellaneous soils of the river flood plains—Continued.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Lomalto clay	Texas	36,544
Lintonia loam [a]	Illinois, Indiana, Kentucky, Mississippi	87,540
Meadow	Alabama, Arkansas, Connecticut, Delaware, Florida, Georgia, Illinois, Indiana, Iowa, Kentucky, Louisiana, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Nebraska, New Hampshire, New Jersey, New York, North Carolina, North Dakota, Ohio, Oklahoma, Pennsylvania, Rhode Island, South Carolina, South Dakota, Tennessee, Texas, Utah, Vermont, Virginia, West Virginia, Wisconsin	2,369,335
Muck and Peat	Kentucky, Louisiana, Nebraska	24,640
Neosho silt loam [b]	Kansas	30,739
Neuse clay	Mississippi, North Carolina	17,952
Point Isabel clay	Texas	4,096
Rio Grande silty clay	do	8,064
Rock outcrop, etc	Indiana, Kentucky, Missouri, North Dakota	20,416
Sanders loam	Texas	17,408
Sanders silt loam	do	10,880
Sarpy clay loam	Nebraska	2,816
Sharkey clay [c]	Louisiana, Mississippi, Texas	760,764
Swamp and Marsh	Alabama, Arkansas, Connecticut, Delaware, Florida, Louisiana, Maryland, Massachusetts, Mississippi, North Carolina, Texas, Virginia.	116,206
Teller fine sand	Oklahoma	1,344
Teller fine sandy loam	do	11,712
Toxaway fine sandy loam	North Carolina, Virginia	25,152
Toxaway loam	North Carolina	11,328
Tyler silt loam	West Virginia	3,008
Yazoo loam [d]	Illinois, Kansas, Louisiana, Mississippi, Missouri, Texas.	168,067
Yazoo sandy loam [e]	Illinois, Indiana, Kansas, Louisiana, Mississippi, Texas.	162,363
Total		4,023,430

[a] The area mapped as Lintonia loam in Tazewell County, Ill., is Wabash loam, that mapped as Lintonia loam in the Dubuque area, Iowa, is Wabash silt loam, and that mapped as Memphis silt loam in Posey County, Ind., and Union County, Ky., is Lintonia loam.

[b] Mapped as Oswego silt loam in Parsons area, Kansas.

[c] The soil mapped as Sharkey clay in Union County, Ky., is the Waverly clay, and that mapped as Sharkey clay in Miller County, Ark., is the Miller clay. The area mapped as Sharkey clay in Allen County and Parsons area, Kansas, is Wabash clay.

[d] The soil mapped as Yazoo loam in Posey County, Ind., is Waverly loam.

[e] The area mapped as Yazoo sandy loam in Clay County, Ill., is Waverly fine sandy loam. In the Austin area, Texas, 1,216 acres of Yazoo sandy loam republished as Bastrop silt loam in Bastrop County, Texas, and included in the latter type.

PIEDMONT PLATEAU.

Lying between the Atlantic Coastal Plain and the Appalachian Mountains and extending from the Hudson River to east-central Alabama is an area of gently rolling to hilly country known as the Piedmont Plateau. On the Atlantic side it is closely defined by the "fall line," which separates it from the coastal plain, but on the northwestern side the boundary is not sharp, although in the main distinct. In its northern extension the Piedmont Plateau is quite narrow, but broadens toward the south, attaining its greatest width in North Carolina.

The surface features are those of a broad, rolling plain that has been deeply cut by an intricate system of small streams, whose valley walls are rounded and covered with soil, although many small gorges and rocky areas occur. The altitude varies from about 300 feet to more than 1,000 feet above sea level.

The extreme northern part of the Piedmont region, in New Jersey, has been glaciated, but elsewhere the soils are purely residual in origin and have been derived almost exclusively from the weathering of igneous and metamorphic rocks. The chief exception is the detached areas of sandstones and shales of Triassic age. Marked differences in the character of the rock and the method of formation has given rise to a number of soil types, those derived from crystalline rocks being the most numerous and widely distributed. Among these the soils of the Cecil and Chester series predominate. The principal types formed from the sandstones and shales are included in the Penn series.

The aggregate area of the soils surveyed in this province is 7,271,798 acres.

Cecil series.

The Cecil series includes the most important and widely distributed soils of the Piedmont Plateau. The heavier members are known as the "red-clay lands" and are characterized by red clay subsoils, with gray to red soils ranging in texture from sand to clay, the lighter colors prevailing with the sandy members. A characteristic of the subsoil is the sharp quartz sand, which is always scattered through it, and occasional veins of quartz or flint rock. Particles and flakes of mica are usually present in the subsoil. The types are of residual origin derived from the degradation of igneous and metamorphic rocks which have been weathered generally to great depths, so that outcrops are rare. Fragments and bowlders of the parent rocks are, however, found on the surface in varying quantities. The topography is rolling to hilly, with level areas existing where stream erosion has not been too great.

The soils of the Cecil series produce general farm crops throughout their extent and in the South cotton is the important crop. Both heavy export and bright tobacco are generally grown, the character of the leaf produced depending on the depth and texture of the soil. The clay is the typical soil of the Piedmont Plateau and occupies two-fifths of the total area of the series, as shown by the surveys to the present time. It is recognized as the strongest soil for general farming. It is adapted to grass, wheat, and corn in Maryland and Pennsylvania, and export tobacco, wheat, and grass in Virginia, cotton, with corn and wheat secondary, in the Carolinas and Georgia. Cowpeas succeed on this soil perhaps as well as anywhere in the country. The sandy loam, while not as strong a soil as the clay, is generally preferred by the farmers on account of greater ease of cultivation. It is the lightest soil of the series suitable for general agriculture. In the South cotton is the leading crop, with corn next in importance. In Virginia and the Carolinas it is used both for bright-yellow and dark-shipping tobacco. Besides these staples a great variety of minor crops is produced. Next in extent is the Cecil sand, which is generally recognized as the bright tobacco soil of the Piedmont region. It is especially adapted to sweet potatoes and watermelons. The silt loam and loam are types of moderate productiveness and are used in the production of corn, cotton, wheat, oats, and tobacco. The fine sandy loam is used chiefly for corn and cotton. It produces fine-textured tobacco, and is also suited to the growing of peaches and plums. The stony loam is found mainly in the more northern States, where it is a good general farming and apple soil. A relatively small area of the clay loam has been mapped. It is an excellent corn soil and produces fair crops of wheat, oats, and hay. So far this soil has been found only in Pennsylvania. Of small extent, the gravelly loam and stony clay have little importance. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Cecil series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Cecil stony loam[a]	Alabama. New Jersey, Pennsylvania, South Carolina.	125,993
stony clay	Alabama, South Carolina	19,136
gravelly loam	South Carolina	23,744
sand	Georgia, North Carolina, South Carolina, Virginia.	259,744
sandy loam	Alabama, Georgia, North Carolina, South Carolina, Virginia.	2,110,808
fine sandy loam	South Carolina, Virginia	186,560
loam[b]	Virginia	112,362
silt loam	North Carolina, South Carolina, Virginia	172,596
clay loam	Pennsylvania	45,376
clay	Alabama, Georgia, Maryland, North Carolina, Pennsylvania, South Carolina, Virginia.	2,135,427
Total		5,191,746

[a] Mapped as Cecil clay (stony phase) in the Lebanon area, Pennsylvania, and as Cecil loam in the Trenton area, New Jersey.

[b] The soil mapped as Cecil loam in Adams County, Pa., Albemarle area, Appomattox County, and Leesburg area, Virginia, and Cecil and Hartford counties, Md., is Chester loam.

Chester series.

The Chester series occurs in the northern part of the Piedmont, having been found and mapped only in Pennsylvania, Maryland, and Virginia. This series differs from the Cecil series in having yellow or only slightly reddish subsoils and gray or brown surface soils, which are on the whole lighter and more friable than those of the Cecil series. The members of this series are also much more micaceous and even more subject to erosion than the soils of the Cecil series. Locally they are known as "gray lands" to distinguish them from the "red lands" of the Cecil series. The topography in general is not so rough, being rolling to moderately hilly.

The soils are of residual origin, derived from igneous and metamorphic rocks, principally mica schists. The weathering has not gone on so deeply as in the case of the Cecil series, and the underlying rock is often encountered within 2 feet of the surface on slopes where erosion is pronounced and rarely lies more than 10 to 15 feet below the surface.

The Chester soils occur with the Cecil series in Pennsylvania, Maryland, and Virginia. They are not so strong as the Cecil soils, and require more careful handling to maintain the yields, but they are generally better developed. Only four members of this series have been mapped. Of this by far the greater area is occupied by the loam. While used mainly for general farming and especially adapted to corn, it is also well adapted to fruit growing, thrifty apple orchards having been found both in Pennsylvania and Virginia. In Maryland it is used for canning crops, sweet corn and tomatoes occupying important positions. The mica loam is devoted to the same crops as the loam, but is a lighter soil and not equal to it in fertility. Although limited in area, the fine sandy loam is a desirable soil for early garden crops and potatoes. Permanent pastures are found over the greater part of the stony loam. Where the surface features are favorable, however, corn, oats, wheat, potatoes, and hay are grown to some extent.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Chester series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Chester stony loam	Pennsylvania	20,864
fine sandy loam	do	6,080
mica loam	Maryland, Pennsylvania, Virginia	65,778
loam[a]	Maryland, Pennsylvania, Virginia, West Virginia	599,976
Total		692,698

[a] Mapped as Cecil loam in Adams County, Pa., Albemarle area, Appomattox County, and Leesburg area, Virginia, and in Cecil and Harford counties, Md.

Penn series.

The Penn series consists of Indian or purplish red soils derived from the weathering of red sandstones and shales of Triassic age. Detached areas of Triassic rocks occur in shallow basins in the Piedmont from New England to South Carolina.

Though of less extent than the Hagerstown and Cecil series, the Penn series comprises some important agricultural soils. The principal type is the Penn loam, a friable loamy soil well suited to general farm crops and considered almost equal to associated limestone soils in productiveness. It is especially adapted to grass and grain and is well suited to dairying. The Penn stony loam is used for orcharding and the less stony areas for general farm crops. Another stony type is the shale loam, which occurs principally in Pennsylvania. It is used for general farming, producing fair crops of corn, wheat, oats, and hay. The sandy loam is easily tilled, but produces only light yields, which are compensated in a measure by uniformly good quality. The silt loam and clay are strong soils, producing fine yields of the general farm crops, wheat, corn, and grass.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Penn series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Penn stony loam	Connecticut, Massachusetts, New Jersey, Pennsylvania, Virginia.	174,788
shale loam	Pennsylvania	100,032
gravelly loam	Maryland, Virginia	704
sandy loam [a]	New Jersey, Pennsylvania, Virginia	60,366
loam	Maryland, New Jersey, Pennsylvania, Virginia	300,746
silt loam	Pennsylvania	61,824
clay [b]	Maryland, Virginia	27,904
Total		726,364

[a] The soil mapped as Penn sandy loam in the Fort Payne area, Alabama, is the Upshur sandy loam.

[b] The soil mapped as Penn clay in the Syracuse area, New York, is Upshur clay.

Miscellaneous soils of the Piedmont Plateau.

The Bradley sandy loam is a residual soil derived mainly from granite and gneiss, modified to some extent by the admixture of sedimentary material. It makes moderate yields of corn, oats, and wheat.

The Brandywine loam is a general farming soil of moderate productiveness.

The Cardiff slate loam occurs in Maryland and Pennsylvania. The interstitial material is rather heavy, but the soil is friable because of the presence of slate fragments. It is mostly forested with oak, chestnut, and other hardwood trees. Cleared areas produce fair crops of corn, wheat, oats, and grass.

The Conowingo barrens is of no agricultural value. The closely related Conowingo clay is a moderately productive soil, used in general farming.

Though extensively developed in Virginia and the Carolinas, the Iredell clay loam, because of a waxy, impervious subsoil, is not esteemed a very desirable soil for any of our common crops. Some areas, however, give fair yields of cotton, corn, and wheat.

The Lansdale silt loam is above the average in productiveness. It is used for the general farm crops.

For corn the Loudoun sandy loam is considered a fine soil. Wheat gives only moderate yields. Grass and clover are also grown with good results.

The Manor loam, found only in Pennsylvania, produces fair yields of the general farm crops, and the Manor stony loam, where cultivation is possible, is used for the same line of agriculture.

Rock outcrop, Rough stony land, Steep broken land, Rough broken land, Riverwash, is mainly nonagricultural land.

The small area of Worsham sandy loam occurs in Virginia. This soil is poorly drained, and is best used for grass, pasture, and hay.

The acreage of the types so far encountered is as follows:

Area and distribution of the miscellaneous soils of the Piedmont Plateau.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Bradley sandy loam	Virginia	59,072
Brandywine loam	Pennsylvania	24,000
Cardiff slate loam	Maryland, Pennsylvania	2,458
Conowingo barrens	Maryland, Pennsylvania, Virginia	15,200
Conowingo clay	Maryland, North Carolina, Pennsylvania, Virginia.	49,894
Iredell clay loam	North Carolina, South Carolina, Virginia.	239,018
Lansdale silt loam	Pennsylvania	99,136
Loudoun sandy loam	Maryland, Virginia	27,968
Manor loam	Pennsylvania	76,736
Manor stony loam	do	38,956
Rock outcrop, Rough stony land, Steep broken land, Rough broken land, Riverwash.	Alabama, Pennsylvania, South Carolina.	20,032
Worsham sandy loam.	Virginia	8,520
Total		660,990

APPALACHIAN MOUNTAINS AND PLATEAU.

The Appalachian Mountains are made up of a number of parallel ranges and intervening valleys, which extend in a general northeast and southwest direction from southern New York to northern Alabama. The elevation ranges from about 1,500 to nearly 7,000 feet above sea level, the highest point being attained in western North Carolina.

Immediately west of the Appalachian Mountains and usually separated from them by a valley is a wide stretch of country known as the Allegheny Plateau. In a broad way this plateau is carved out of a great block of sedimentary rocks tilted to the northwest from the mountains. It is crossed by numerous streams. As they run in deep channels (all the larger ones being from 200 to 1,000 feet in depth) the dissection of the plateau block is often minute.

The rocks of the eastern ranges of the Appalachian Mountains are igneous or metamorphic in origin, while the western ranges, as well as the Allegheny Plateau, are made up of sedimentary rocks. Different series of soils have, therefore, been formed in different parts of these mountains and plateau. The igneous and metamorphic rocks give rise to the soils of the Porter series, while the Dekalb and Upshur series are formed from the weathering of the sandstones and shales of sedimentary origin.

The character of the topography in the mountain and much of the plateau region is such that general farming is not practicable. These areas are, however, well suited to grazing and fruit growing, and these are very important industries.

The aggregate area of all the soils surveyed in this province is 6,367,009 acres.

Dekalb series.

The Dekalb series is derived from the disintegration of sandstones and shales, from Silurian to Carboniferous in age. The surface soils are gray to brown in color, while the subsoils are commonly some shade of yellow. The surface features consist of gently rolling tablelands, hills, and mountains.

The soils of this series are generally not very productive.

The stony and sandy members of the series are well adapted to orchard and small fruits, while the heavier soils make good hay and pastures. The yields of the cereal crops are small, but the quality of the products in general is good. The stony loam and stony sandy loam, owing to character of surface and the very stony nature, are not desirable soils to cultivate, but with proper location and elevation have proven well adapted to peaches. The shale loam is a heavy soil, and is adapted to grain and grass crops. In most localities it is devoted entirely to these crops. The yields are fair. The gravelly loam does fairly well for the general farm crops, but is generally droughty. The gravelly and fine sandy loam are fairly good soils for truck and fruit. The loam is a naturally well-drained soil, and is the best general farming soil in this series, producing potatoes, vegetables, melons, small fruits, and tobacco, as well as the general farm crops. The silt loam and clay are heavy soils that do best to the grain and grass crops, but because of the hilly surface much of these types should not be cultivated. As a whole, the soils of the Dekalb series are covered to great extent by forest growth, the predominant growths being chestnut and oak and other hardwood trees of less prominence.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Dekalb series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Dekalb stony loam	Alabama, Maryland, North Carolina, Pennsylvania, Tennessee, Virginia, West Virginia.	749,396
shale loam	Kentucky, Maryland, Tennessee, Virginia, West Virginia.	481,012
gravelly loam	Pennsylvania	4,800
stony sandy loam	do	18,688
sandy loam	Alabama, Ohio, Pennsylvania, Tennessee, West Virginia.	539,796
fine sandy loam	Alabama, Kentucky, Missouri, Pennsylvania, Virginia.	113,344
loam	Kentucky, Pennsylvania, West Virginia	102,336
silt loam	Alabama, Indiana, Kentucky, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia	701,568
clay[a]	Alabama, New York, Ohio, Pennsylvania, West Virginia.	153,380
Total		2,864,320

[a] Mapped as Dunkirk shale loam in the Westfield area, New York.

Fayetteville series.

The Fayetteville series consists of grayish-brown to brown soils with yellowish-brown to reddish-brown subsoils. They are intermediate between the Dekalb series and the Upshur series. They are formed by the weathering of sandstones and shales and are found throughout a large part of western and northwestern Arkansas and eastern Oklahoma. They are considered moderately fertile soils.

The stony loam is the most extensively developed. The surface is rolling to hilly and in some places the slopes are subject to injurious washing. The least stony parts are fairly well adapted to the production of general farm crops, and in favorable positions apples and peaches do well. Grapes are also grown in some sections with success. Under the present conditions the more hilly and stony areas can best be utilized as pasture. Where the topographical position is favorable, the fine sandy loam is exceptionally well suited to peaches. Apples and small fruits, especially strawberries, do well. Moderate yields of the general farm crops are readily obtained and it is considered the best potato soil in this section. The loam is a good general farming soil, and satisfactory yields of corn, oats, wheat, and grass may be readily secured where the type is efficiently farmed. Its productiveness is much better maintained than the fine sandy loam. Excellent yields of strawberries are secured on the well-drained portions, but they are not quite as early as those grown on the fine sandy loam. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Fayetteville series.

Soil name.	State in which each type has been found.	Total area.
		Acres.
Fayetteville stony loam	Arkansas	118,400
fine sandy loam	do	17,216
loam	do	44,352
Total		179,968

Porter series.

The Porter series includes the residual soils of the Appalachian Mountains derived from igneous and metamorphic rocks. The soils are analogous to those of the Cecil series, but are classed separately on account of the difference in topographic position. The mountainous character of the country in which the Porter soils are found renders them difficult of cultivation. They occur at high elevations and so are influenced more or less by different climatic and drainage conditions.

The soils of the Porter series are all eminently adapted to fruit culture, except the higher and rougher portions, and especially so at medium elevations and under suitable conditions of slope and exposure. Fruit forms the principal crop and the industry seems destined to take on much larger proportions. The black loam is the most prominent, being especially adapted to the production of the Albemarle Pippin apple, which attains perfection in the sheltered coves having a northeasterly exposure. On the broad, rolling tops of the mountains the situation is too high and exposed for fruit culture, but such areas make excellent grazing. The loam, clay loam, and clay are the general farming types of the series, but the Porters clay is also important as an apple soil, producing the red varieties of apples, as the Winesap and others, to perfection. The sandy types, where not too rough or at too high elevation, are especially adapted to peach culture and are so used extensively. A number of varieties of peaches succeed on these soils. They will also produce good crops of grapes. Cattle grazing is also an important industry of the Porters series of soils, and on the more level and less elevated areas the general farm crops, as wheat, corn, rye, and barley, are grown. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Porter series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Porters stony loam	Georgia, North Carolina, Pennsylvania	81,734
sand	North Carolina, South Carolina, Virginia	216,710
sandy loam	do	893,305
fine sandy loam	South Carolina	24,128
black loam	North Carolina, Virginia	198,550
loam	North Carolina, South Carolina	436,160
clay loam	South Carolina	26,432
clay	North Carolina, Pennsylvania, South Carolina, Virginia, West Virginia.	292,509
Total		1,664,528

Upshur series.

The Upshur series is closely associated with the Dekalb series, but is much less extensively developed. It is characterized and distinguished from the Dekalb series by brown and red surface soils and red subsoils. The series has been formed by the weathering of red sandstones and shales of Paleozoic age. The surface is rolling to mountainous, and drainage is well established.

The soils of the Upshur series are generally more productive than the corresponding members of the Dekalb series. The sandy loam and loam are well drained, and when well cultivated yields fairly good crops of cotton, corn, wheat, and the forage crops. The clay is a heavy soil, and occurring on steep hillsides suffers much from erosion. It is mainly used for pasturage, but the less hilly areas, susceptible of thorough cultivation, produce good crops of wheat, corn, and grass. The stony loam, stony sandy loam, and sandy loam are adapted to fruit. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Upshur series.

Soil name.	States in which each type has been found.	Total area,
		Acres.
Upshur stony loam	Arkansas, Pennsylvania	62,912
stony sandy loam	Pennsylvania	2,368
sandy loam[a]	Alabama, Arkansas	8,896
fine sandy loam	Arkansas	17,472
loam	Alabama, Arkansas, Pennsylvania	28,416
silt loam	Virginia	2,624
clay[b]	New York, Ohio, West Virginia	41,216
Total		163,904

[a] Mapped as Penn sandy loam in Fort Payne area, Alabama.
[b] Mapped as Penn clay in Syracuse area, New York.

Miscellaneous soils of the Appalachain Mountains and Plateau.

The Chandler stony loam is of little agricultural value, hardly at all developed, and is covered with forest-growth.

Very little of the Chemung stony loam is under cultivation, although it is fairly productive. This is largely due to its rough and rolling topography. It may prove a valuable fruit soil.

A steep ridge soil, the Clinch shale loam has little value except for pasturage.

The Conway silt loam is a transitional type between uplands and flood plains. It is not generally adequately drained, but where moisture conditions are properly controlled good crops of cotton and corn may be grown.

The Grainger shale loam, so far as encountered, is a rough ridgy soil and fit only for grazing stock.

Corn and wheat are the principal crops of the Holston loam. It is not considered a productive soil.

The Lickdale clay loam is low-lying and naturally refractory land, and best suited to grass and pasturage. The stony loam is a poor soil, but with improvement; through careful cultivation, it might be used in some areas for peach culture.

The Meigs clay loam is a comparatively extensive soil in southeastern Ohio, where it is used both for pasture, being naturally adapted to bluegrass, and for growing wheat, oats, and hay. It is not a very strong soil, but responds to fertilization and good treatment.

The Morrison sand forms a part of what are locally known as the "barrens," in the limestone valleys of Pennsylvania. It is of very low agricultural value and adapted mainly to forestry.

The Morrison fine sandy loam is not adapted to general farming, and the yields of corn, wheat, and oats are comparatively low. It is of very limited occurrence.

The Morrison sandy loam, which occupies ridges and slopes in the "barrens" of Pennsylvania is not adapted to general farming, but should be suited to trucking and the production of fruits. Pears in the area surveyed in Pennsylvania appeared especially thrifty.

Very little of the Montevallo stony loam is under cultivation. The cleared areas give small yields of cotton. Some areas may some day prove valuable for peach culture.

The Pilot loam produces average yields of corn, wheat, oats, grass, and forage crops. The Pilot gravelly loam is for the most part incapable of cultivation on account of gravel and stone content, otherwise it makes fair yields of the general farm crops.

Rock outcrop, Rough stony land, Steep broken land, Rough broken land, and Riverwash, are mainly nonagricultural land.

The Talladega slate loam is extensively developed in Alabama, but the greater part of it is still wild land. Cleared areas are used for cotton and corn. The stony loam is largely under cultivation to cotton, making fair yields. With better market facilities, it would be a valuable soil for peach and small fruit culture.

The Paris loam and Indian loam are unimportant soils.

The acreage of the types so far encountered is as follows:

Area and distribution of the miscellaneous soils of the Appalachian Mountains and Plateau.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Chandler stony loam	Alabama	1,664
Chemung stony loam	Pennsylvania	3,328
Clinch shale loam	Tennessee	26,752
Conway silt loam	Arkansas	38,912
Grainger shale loam	Tennessee	20,288
Holston silt loam	Tennessee, Virginia	576
Holston loam	Tennessee	1,472
Indian loam	Virginia	384
Lickdale clay loam	Pennsylvania, Tennessee	33,040
Lickdale stony loam	Alabama	4,416
Meigs clay loam	Ohio	395,712
Montevallo stony loam	Alabama	4,032
Morrison fine sandy loam	Pennsylvania	1,600
Morrison sand	do	576
Morrison sandy loam	do	2,560
Paris loam	Virginia	1,536
Pilot gravelly loam	do	2,752
Pilot loam	South Carolina, Virginia	42,752
Rock outcrop, Rough stony land, Rough broken land, Riverwash.	Alabama, Arkansas, Kentucky, North Carolina, Ohio, Pennsylvania, South Carolina, Tennessee, Virginia, West Virginia.	800,833
Talladega slate loam	Alabama	95,552
Talladega stony loam	do	15,552
Total		1,494,289

LIMESTONE VALLEYS AND UPLANDS.

The limestone soils are among the most extensively developed of any in the United States and occur in both broad upland and inclosed narrow valley areas. The greatest upland development is seen upon the Cumberland Plateau in eastern Tennessee and Kentucky and upon the Carboniferous formation in central Tennessee and Kentucky, northern Alabama and Georgia, and in Missouri. The valley soils are found principally in Pennsylvania, Maryland, and Virginia, and in the mountain section of eastern Tennessee and Kentucky and northern Alabama and Georgia. The topography of the plateau soils varies considerably. In the Cumberland Plateau and Highland Rim the surface is undulating; in the region of the Ozark uplift in Missouri and Arkansas it is quite rough and hilly, and where there is an elevation of the surface, or where the plateau is deeply dissected by erosion, it presents a quite mountainous topography. The valley soils of the Appalachian region also show considerable topographic relief, sometimes exhibiting mountainous surface features.

The limestone soils are residual in origin, being derived from the weathering in place of limestone of differing age and composition. This is accomplished by the removal through solution of the calcium carbonate of the limestone, leaving behind the more resistant siliceous minerals. These soils are remarkable for the fact that they contain but a very small percentage of the original limestone rock, the larger part having gone into solution. It has thus required the solution of many feet of rock to form a single foot of soil. Thus far the limestone soils east of Kansas and Texas and north of central Alabama and Georgia have been grouped in two important series, known as the Hagerstown and Clarksville.

The aggregate area of the soils surveyed in this province is 6,052,926 acres.

Clarksville series.

The Clarksville series is derived largely from cherty and fossiliferous limestone of the St. Louis group of the Subcarboniferous formation. These soils occur in both the level and undulating uplands and in rough, hilly country with steep valleys. When the latter surface features predominate the soils are generally unproductive and very stony, but in some sections are adapted to fruit, especially apples. The soils formed from beds of purer limestone occupying level and gently rolling areas are, as a rule, very productive, and are adapted to wheat, corn, and tobacco.

The soils of the Clarksville series are not nearly so productive as those of the Hagerstown, yet they are important agriculturally as producing special crops. The stony loam and silt loam, usually occurring together, are the most extensive and widely distributed of the series. The former has become prominent in the fruit industry in the Ozark Plateau region, where it is extensively used in the production of apples and peaches. The silt loam is generally known as "Barrens" and "Flatwoods," and is largely forested, but late years have seen the specializing of cantaloupe and strawberry growing on this soil in the Highland Rim region of Tennessee. In Tennessee and Kentucky this soil produces an excellent grade of export tobacco. It is a droughty soil and not considered strong, but with good treatment fair yields of the staple crops can be produced. The clay loam is a strong, fertile soil and considered the best general farming soil of the series. It produces heavy yields of the export variety of tobacco, but not a superior quality of leaf. A large part of these soils is forested, the growth consisting mostly of oaks, but other trees are also represented. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Clarksville series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Clarksville stony loam [a]	Alabama, Arkansas, Missouri, Tennessee	2,277,140
gravelly sandy loam	Alabama	5,376
fine sandy loam	do	1,856
loam	Alabama, Tennessee	86,720
silt loam	Alabama, Arkansas, Kentucky, Missouri, Tennessee.	1,215,362
clay loam [b]	Kentucky, Tennessee	36,868
Total		3,623,322

[a] The soil mapped as Clarksville stony loam in the Dubuque area, Iowa, and Wichita area, Kansas, is now classed as Rough stony land.

[b] The soil mapped as Clarksville clay loam in Lauderdale County, Ala., and Lawrence County, Tenn., is the Hagerstown loam.

Cumberland series.

Many of the larger streams traversing the limestone regions formerly flowed at considerably higher levels, and this resulted in the formation of more or less distinct erosion terraces. Upon these terraces was deposited a thin stratum of sedimentary material. The surface soils are therefore partly sedimentary, while the subsoils are residual from the underlying limestones. The surface soils are brown to yellowish brown in color, while the subsoils are yellow to reddish yellow.

The Cumberland series comprise high terrace soils in the limestone region of the South. The loam is adapted to the general farm crops, to truck, and to fruit. In its more southern areas cotton is an important and very profitable crop. A small area of fine sandy loam has been mapped. This member of the series is used chiefly for corn and cotton, but is also adapted to small fruits and vegetables, though these latter crops are not grown on the areas encountered to the present time. Only a limited area of the gravelly loam and clay loam has been found.

The acreage of the types so far mapped is as follows:

Area and distribution of the soils of the Cumberland series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Cumberland gravelly loam	Virginia	3,840
fine sandy loam	Alabama	4,864
loam	Kentucky, Tennessee, Virginia	60,480
clay loam	Virginia	192
Total		69,376

Decatur series.

The Decatur series consists of reddish-brown to red soils with intensely red or blood-red subsoils. The deep-red color forms their distinguishing characteristic. They are derived from rather pure hard limestones, and outcrops of the underlying rock are not uncommon. They form valley lands occurring principally in east Tennessee and Alabama.

The Decatur soils have an agricultural value intermediate between the Hagerstown and the Clarksville series. The clay, which has been found only in Tennessee, and a great part of which is not under cultivation, makes excellent bluegrass pasture. Less stony areas produce moderate yields of corn and wheat. On the other hand, the clay loam is an excellent general farming soil. In Tennessee it gives good crops of wheat, oats, and grass and other forage crops. In Alabama it is a strong cotton soil, and is also good grass land, heavy yields of both orchard and Johnson grass being secured. The silt loam, while a good general farming type, has been found to be especially well adapted to cantaloupes. The loam likewise is a fine general farming soil. It produces good crops of cotton and corn. Cotton and corn are also produced to advantage on the stony loam, which in addition, in lighter phases, is well adapted to peach culture. Some fine commercial orchards are established on this soil.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Decatur series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Decatur stony loam	Alabama	85,696
loam	do	25,664
silt loam	Tennessee	960
clay loam	Alabama, Tennessee, Virginia	63,104
clay [a]	Tennessee	15,040
Total		190,464

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[a] The soil mapped as Decatur clay in the Greenville area, Tennessee, is Hagerstown clay.

Hagerstown series.

The Hagerstown series is formed mainly from the solution and subsequent filtration of pure massive limestone of Cambro-Silurian age. The soils of this series, as a rule, occur in valleys bordered by areas of the more resistant sandstones and shales. The series is most typically developed in the limestone valleys of the Allegheny Mountain region and in the central basins of Kentucky and Tennessee, but smaller areas are found as marginal deposits in the adjoining Piedmont section and in the deep valleys of the Appalachian Plateau, where the underlying limestones have been exposed to weathering by previous deep erosion. The most productive valley phase occurs in the large valley between the Blue Ridge and the Allegheny Mountains.

The important loam and clay types form the greater part of the Hagerstown soils so far covered by the soil survey. It is these two soils that have given agricultural prominence to the limestone valleys of the eastern United States. The production of wheat has continued upon these soils notwithstanding the competition of the wheat lands of the West. They constitute the bluegrass region of Kentucky and Tennessee and comprise the lands of the important Burley tobacco district. The loam is the typical upland corn soil of the valley region of central Pennsylvania, Maryland, and the Shenandoah Valley of Virginia. Important tomato-canning industries have been developed in sections. As an apple soil it has produced, par excellence, the Winesap, York Imperial, and some other varieties, and extensive commercial orchards are found. The clay loam is recognized as one of the strongest soils for general agricultural purposes and is well known for its large crops of wheat, corn, and grass. The stony and sandy soils have a special adaptation for fruit, commercial orchards of peaches and apples being established in many sections of the valley region.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Hagerstown series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Hagerstown stony loam	Alabama, Pennsylvania, Tennessee, Virginia	288,494
stony clay	Alabama, Kentucky, Tennessee	50,432
sandy loam	Alabama, Pennsylvania, Tennessee, Virginia, West Virginia.	74,246
loam[a]	Alabama, Kentucky, Tennessee, Pennsylvania, Virginia.	1,045,702
silt loam	Pennsylvania, Virginia	54,592
clay loam	do	28,936
clay[b]	Alabama, Kentucky, Pennsylvania, Tennessee, Virginia, West Virginia.	347,482
Total		1,889,884

[a] Mapped as Clarksville clay loam in Lauderdale County, Ala., and Lawrence County, Tenn., and as Davidson loam in Davidson County, Tenn.

[b] Mapped as Decatur clay in the Greeneville area, Tennessee.

Miscellaneous soils of the limestone valleys and uplands.

The Brooke clay loam is a limestone soil found in West Virginia in the region bordering the Ohio River. It has considerable value for general farm crops.

The Conestoga loam of Lancaster and Montgomery counties, Pa., is recognized as an excellent soil for general agriculture. Though a very refractory soil, its known high productiveness for wheat and grass makes the Conestoga clay one of the most desirable soils in the Shenandoah Valley of Virginia.

The Davidson loam is a limestone soil, modified by material derived from strata of sandstone and shale. It is used for the same crops as the Hagerstown loam.

The Fort Payne clay loam is an undesirable soil and best suited for pasturage. The sandy loam on the other hand is a valuable soil found in Michigan. It is suited to a variety of crops, and has a marked adaptation for potatoes, which are of superior quality. Besides the general farm crops it is well fitted to produce sugar beets and other special crops.

The Guthrie clay and silt loam constitute the "crawfish lands" occupying depressions in limestone areas. While of some value for their timber growth, they are extremely poor soils for agricultural purposes in their present undrained condition.

The disintegration of the water-lime rocks in Pennsylvania gives rise to the Frankstown stony loam, a soil easily tilled and quite generally cultivated. It is devoted to general farm crops, of which wheat and corn yield well. This soil should be used more extensively for clover, pasture, or meadow in order to increase the humus and prevent washing and leaching.

The Moccasin stony clay occupies steep slopes with outcropping limestone. It is difficult to cultivate and is best suited to stock raising.

The Murrill clay loam produces good crops of wheat, corn, grass, and dark shipping tobacco.

The Newman stony loam has very limited extent; being rough it is little suited to cultivated crops. Grazing is its principal use.

The Radford loam is a high terrace soil of moderate productiveness. It is used chiefly for corn and wheat, with hay as a secondary crop. Some of it is used for pasture. It has a wide range in value, the poorer areas being valued at $10, and from this the price ranges to $100 an acre.

Rock outcrop, Rough stony land, Steep broken land, Rough broken land, and Riverwash are mainly nonagricultural land.

The acreage of the types so far encountered is as follows:

Area and distribution of the miscellaneous soils of the limestone valleys and uplands.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Brooke clay loam	West Virginia	38,464
Conestoga clay	Tennessee, Virginia	64,128
Conestoga loam	Pennsylvania	52,344
Davidson loam[a]	Tennessee	20,352
Fort Payne clay loam	do	9,536
Fort Payne sandy loam	Michigan	7,936
Frankstown stony loam	Pennsylvania	2,048
Guthrie clay[b]	Alabama, Arkansas, Kentucky, Tennessee.	53,608
Guthrie silt loam	Alabama, Tennessee	448
Moccasin stony clay	Tennessee	3,840
Murrill clay loam	Virginia	15,720
Newman stony loam	Tennessee	896
Radford loam	Virginia	704
Rock outcrop, Rough stony land, Steep broken land, Rough broken land, Riverwash.	Missouri, Tennessee	9,856
Total		279,880

[a] The soil mapped as the Davidson loam in Davidson County, Tenn., is the Hagerstown loam.

[b] The soil mapped as Guthrie clay in Posey County, Ind., is Waverly clay loam.

GLACIAL AND LOESSIAL REGIONS.

The soils of the glaciated part of the country constitute one of the most important groups in the United States. This group includes all soils derived directly from till or loess. The soils formed from the till are confined to that part of the country lying north of the southern limit of glacial action, but the loess soils occur also south of this line, especially along the Mississippi and Ohio rivers and in Kansas and Nebraska. The line of the southern extension of the ice sheet touches the Atlantic coast about New York City, passes through northern New Jersey, southern New York, and northwestern Pennsylvania, swings southwestward through Ohio to Cincinnati, crosses the Mississippi River at St. Louis, and follows the south side of the Missouri River into Montana, where it crosses the Canadian boundary line, then dips southward into Idaho as a long lobe in the mountainous nonagricultural region, and crosses the northwestern part of Washington, including the Puget Sound region.

Practically all of the United States north of this line was covered in recent geological time by a great continental glacier, many hundreds, and even thousands, of feet in thickness. This great ice sheet, moving in a southern direction, filled up valleys, planed off the tops of hills and mountains, ground up the underlying rocks, carried the derived material both within and upon the ice, and finally deposited the gravel, sand, silt, and clay as a mantle, varying in thickness from a few feet to more than 300 feet. Often this material has been transported hundreds of miles, and is wholly unrelated to the underlying rocks, but in some places the movement has been slight, and the drift consists very largely of the ground-up underlying rock. Over a large proportion of the area covered by the drift and also along the Ohio and Mississippi rivers and in Kansas and Nebraska the surface material consists of a fine silty deposit, known geologically as " loess " and " plains marl." In the classification of the glacial soils three important series—Miami, Marshall, and Volusia—having distinct characteristics have been recognized, and, in addition, quite a number of miscellaneous soils which can not be put in any series.

The aggregate area of the soils surveyed in this province is 22,417,832 acres.

Marshall series.

The Marshall series includes the dark-colored upland glacial and loessial soils, which cover almost all of the great prairie region of the central West. The soils of this series are characterized and distinguished from those of the Miami series by the relatively large quantity of organic matter in the surface soils, which gives them a dark-brown to black color. The topography is level to rolling, and artificial drainage is necessary on many level and low-lying areas to secure the best results. The soils of this series are very productive and constitute the great corn soils of the country.

The Marshall silt loam, loam, and clay loam constitute the principal soil types throughout the great corn belt and rank among the most productive of our general farming soils. In Iowa, Illinois, and Nebraska corn, oats, clover, and timothy are the leading crops, while in Minnesota and the Dakotas wheat becomes of primary importance. The Miami black clay loam when drained is also an exceedingly fertile soil, being particularly well adapted to corn. The sandy loam and fine sandy loam, while not so well adapted to general farming as the heavier soils, are quite productive and have a wide crop adaptation. The sand and fine sand are well suited to truck crops, but give rather uncertain yields of general farm crops.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Marshall series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Marshall stony loam	North Dakota, South Dakota	84,096
gravel [a]	Minnesota, North Dakota	2,560
gravelly loam	Kansas, Minnesota, North Dakota, Wisconsin	106,816
sand	Indiana, Iowa, Wisconsin	52,736
fine sand	Indiana, Iowa, Minnesota, Nebraska, North Dakota.	54,272

[a] The soil mapped as Marshall gravel in Pontiac area, Michigan, is Miami gravelly sand.

Area and distribution of the soils of the Marshall series—Continued.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Marshall sandy loam	Illinois, Indiana, Kansas, Minnesota, South Dakota.	261,440
fine sandy loam	Indiana, Minnesota, Nebraska, North Dakota	111,168
loam	Illinois, Indiana, Iowa, Michigan, Minnesota, Nebraska, North Dakota, South Dakota, Wisconsin.	1,680,832
silt loam[a]	Colorado, Illinois, Indiana, Iowa, Kansas, Louisiana, Minnesota, Missouri, Nebraska, North Dakota, Wisconsin.	4,454,470
clay loam	Iowa, Minnesota, North Dakota, Wisconsin	600,320
black clay loam[b]	Illinois, Indiana, Iowa, Michigan, Minnesota, North Dakota, Ohio, South Dakota, Wisconsin.	572,176
clay	North Dakota	76,800
Total		8,057,686

[a] Mapped as Miami silt loam in Clinton and St. Clair counties, Ill., and as Fresno fine sandy loam in Lower Arkansas Valley area, Colorado.

[b] The soil mapped as Miami (now Marshall) black clay loam in the Toleda area, Ohio, is Clyde clay.

Miami series.

The Miami series is one of the most important, widely distributed, and complete soil series that has been established. The series is characterized by the light color of the surface soils, by derivation from glacial material, and by being timbered either now or originally. The heavier members of the series are better adapted to wheat than the corresponding members of the Marshall series, but they do not produce as large yields of corn.

The clay loam is the most important for general farming, and forms the principal type of soil in western Ohio and central and eastern Indiana. It is especially well adapted to small grain and grass crops. The silt loam is more rolling and hilly than the clay loam and is not so well suited to general farming. Wheat does better upon it than upon the Marshall silt loam, with which it is closely associated, but the yields of corn are considerably less. It is also well adapted to fruit, especially apples. The sandy loam and fine sandy loam are used for general agriculture, but are especially adapted to medium and late truck crops and fruit. The loam is suited to corn and potatoes, while small grain and grass are grown, but with less success than upon the clay loam. Strawberries and raspberries, as well as other small fruits, do well on this type. The stony sand, gravelly sand, and gravel are not of much agricultural value under present conditions. The stony loam is a good general farming soil, is also well adapted to apples, and furnishes excellent pasture, while in New York alfalfa is grown upon it very successfully. The stony sandy loam and gravelly sandy loam are not strong soils, but are fairly well suited to light farming, fruit, and truck. The sand and fine sand are not adapted to general farming, but are the best early truck soils of this section.

The acreage of the different types so far encountered is as follows:

Area and distribution of the soils of the Miami series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Miami stony sand	Michigan, New York, Washington. Wisconsin	100,278
stony sandy loam	New York, Rhode Island, Vermont, Washington	267,328
stony loam	Michigan, Minnesota, New York, Ohio, Rhode Island, Washington, Wisconsin.	879,094
gravel	Illinois, Wisconsin	21,376
gravelly sand [a]	Michigan, Washington	91,242
gravelly sandy loam	Indiana, Michigan, Minnesota, Washington	58,624
gravelly loam [b]	Indiana, Michigan, Ohio	71,282
sand	Indiana, Kansas, Michigan, Minnesota, Nebraska, Ohio, Wisconsin.	795,720
fine sand	Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, New York, Wisconsin.	263,564
sandy loam [c]	Indiana, Iowa, Michigan, Minnesota, Ohio, Washington. Wisconsin.	745,460
fine sandy loam [d]	Indiana, Michigan, New York	180,816
loam [e]	Indiana, Michigan, Wisconsin	214,720
silt loam [f]	Illinois, Indiana, Iowa, Kentucky, Missouri, Nebraska, Rhode Island, Wisconsin.	1,951,488
clay loam [g]	Indiana, Iowa, Michigan, Ohio, Washington, Wisconsin.	1,881,818
Total		7,422,760

[a] Mapped as Marshall gravel in Pontiac area, Michigan.

[b] The soil mapped as Miami gravelly loam in the Big Flats area and Syracuse area, New York, is the Dunkirk gravelly loam.

[c] The soil mapped as Miami sandy loam in the Grand Forks area, North Dakota, is the Clyde fine sandy loam; in the Montgomery County area, Ohio, is Wabash sandy loam; and in Posey County area, Indiana, is Wabash fine sandy loam.

[d] The soil mapped as Miami fine sandy loam in Posey County, Ind., and Union County, Ky., is Waverly fine sandy loam; in the Boonville area, Indiana, is the Norfolk fine sandy loam; in the Lyons and Syracuse areas, New York, is Dunkirk fine sandy loam; and in St. Claire County, Ill., is Memphis silt loam.

[e] The Miami loam in the Auburn, Lyons, and Syracuse areas, New York; the Columbus, Coshocton, Montgomery, Toledo, and Westerville areas, Ohio; the Fargo and Grand Forks areas, North Dakota; the Marshall, Minnesota, and Pontiac areas, Michigan; and the Viroqua area, Wisconsin, is Wabash loam. The soil mapped as Miami loam in Tazewell County, Ill., is Sioux loam, and that mapped as Miami loam in the Janesville area, Wisconsin, is the Sioux sandy loam.

[f] The soil mapped as Miami silt loam in the Syracuse area, New York, is Dunkirk silt loam, and that mapped as Miami silt loam in Clinton and St. Claire counties, Ill., is Marshall silt loam.

[g] The soil mapped as Miami clay loam in Toledo area, Ohio, is Dunkirk clay loam, and that mapped as Miami clay loam in the Stuttgart area, Arkansas, is Crowley silt loam.

Volusia series.

The soils of the Volusia series are derived from the feeble glaciation of the shales and sandstones of the Devonian and the Upper Carboniferous rocks of eastern Ohio, southern New York, and northern Pennsylvania. In all cases the underlying shales and sandstones have given rise to a large proportion of the soil material, and this has been modified to a varying degree by glacial material brought in from other regions.

Topographically the soils of the Volusia series occupy the upland portion of the plateau country which slopes north and west from the Allegheny Mountains. In the higher, more easterly portions of the glaciated section of the plateau deep preglacial erosion has cut the upland into blocky rounded or flat-topped hills separated by deep, steep-sided gorges. Farther west, where the elevations are less, this topographic feature is not so pronounced, and the series occupies rolling hills divided by deep valleys. Under cultivation all of the soils of the series are well adapted to the production of potatoes, timothy, and small grains, particularly oats and buckwheat. At lower elevations wheat and corn give good yields.

The Volusia loam and silt loam are the most important types of the series. The surface of the loam is less rolling than that of the silt loam. The former is well adapted to the production of potatoes, grass, oats, buckwheat, and corn in less elevated portions. Apples are also grown to advantage throughout a considerable part of its extent. The silt loam occupies rolling and hilly land and is frequently interrupted or bordered by steep slopes not suited to agricultural purposes. Where properly cultivated it is a good soil for timothy and small grain. Owing to the hilly character of the country, transportation by wagon is rather difficult, and the type should be used more for the raising of cattle and sheep, in order to utilize its known capabilities for the production of hay and oats, rather than for the growing of bulky grain products which must be hauled to market at considerable cost. The stony loam is rather above the average of the other members of the series for general farming. On well-drained areas, particularly on northern and northwestern slopes, apple orchards are highly successful. The gravelly loam and clay loam, while only of very limited occurrence, are good soils, the former being particularly adapted to apples and the latter to grasses. There are large areas of these soils which are not as highly developed as they should be or as they have been in the past. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Volusia series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Volusia stony loam	New York	12,352
gravelly loam	do	4,608
loam	New York, Ohio	464,674
silt loam	Indiana, New York, Ohio	569,984
clay loam	New York	5,952
Total		1,057,570

Miscellaneous soils of the glacial and loessial regions.

The Allis clay, which is a residual soil derived from the weathering of light-colored shales, is adapted to general farm crops and to dairy farming. Corn, oats, and hay are the principal crops grown, and all do well.

The Allis shale loam is closely related to the clay, but contains a large percentage of shale fragments. The type occupies steep slopes and is well adapted to grains and grasses. Owing, however, to its rough topography it is probably best used as pasture.

The Barnum loam is closely associated with the stony loam. The surface is rolling and natural drainage is usually good. It is derived from the " red till," and is adapted to hay, oats, and wheat.

The Barnum stony loam has a rolling and hilly surface and constitutes a part of what is known as the " red till." Where not too rough and stony it is adapted to oats, hay, and wheat.

The Bellingham silt loam occupies small, poorly drained basins. It is used chiefly for growing hay, but when underdrained it produces good yields of vegetables. Both clover and timothy do well on this type.

The Bernardstown loam occurs in very broken and hilly areas and outcrops of the underlying argillaceous rocks are very common. It is very productive, being particularly fine for grass and grazing, and also produces excellent crops of corn, oats, and rye.

The topography of the Bloomfield sandy loam varies from gently rolling hills to hummocks consisting of small mounds and narrow ridges of low relief. It produces fairly good crops of corn, wheat, rye, and clover, while truck crops and also tree fruits, such as cherries, apples, and peaches, do well.

The Cassadaga sand occurs usually in upland valleys and is commonly wooded. The soil is inclined to be wet and marshy and is in need of drainage. Very little of this type is under cultivation and it has at present little agricultural value. If it were cleared and drained it would probably be suited to grass.

Custer loam produces fair yields of oats and hay, and when well cultivated the better drained areas produce good yields of potatoes and other vegetables. The average yield of clover is estimated at 2 to 3 tons, and of oats at about 40 to 50 bushels per acre. When drained its agricultural value will be greatly increased.

The Custer silt loam is a very productive soil. The principal crops are oats and hay, the former averaging 50 to 60 bushels per acre, although as high as 80 or 100 bushels have been secured. Timothy and clover do well, producing 2 to 3 tons, but 3½ to 4 tons is not an uncommon yield. Canadian field peas are successfully grown, yielding 40 to 50 bushels per acre. Irish potatoes do well on well-drained land, often yielding 300 to 400 bushels. Tree fruits and small fruits, and beets, peas, cabbage, and other truck make profitable yields.

The Dover fine sandy loam is a light, friable soil, and were it not for the rough surface and outcrops of the underlying dolomite would be easy to cultivate. The type is quite productive, but is devoted largely to pasture.

The Dover loam is considered a strong soil for all general farm crops grown in the section where it occurs, and is especially prized for pasture. It is also fairly well adapted to fruit.

The Dutchess silt loam is practically all cleared and cultivated, being used principally for pasture and hay. Fruits, especially apples, are also grown with success where position and climatic conditions are favorable.

The surface of the Dutchess slate loam is rather broken and hilly, and outcrops of the underlying slate are frequent. It is largely devoted to grass and makes good hay and pasture. In general it is considered a thin soil, requiring fertilization to give the best yields.

Except where fruit is grown, the Dutchess stony loam is not generally desired as farming land because of its rough surface. It seems peculiarly adapted to the growing of violets, and supplies the soil for the greenhouses about Rhinebeck, N. Y. Grass does well and the type makes good pasturage.

The Gloucester loam, which has resulted from the feeble glaciation of mica schists, is considered an especially strong soil for grass, and large crops of timothy, redtop, and clover hay are harvested. The sections where it occurs are therefore largely devoted to dairying.

The Gloucester stony loam constitutes a considerable proportion of the glacial soils of New England. Very little of it is cleared and under cultivation, and it is covered for the most part with a stunted growth of chestnut oak, white birch, and undergrowth. Some corn and potatoes are produced, but only light yields are obtained. In Merrimack County, N. H., it is used to considerable extent for the production of hay and for pasture. The type as a whole is best suited to forestry and pasture, though in some places orcharding should be profitable.

The Gloucester stony sandy loam occurs throughout a large portion of New England and consists of glacial material composed principally of crystalline rocks. The type occupies the tops and slopes of hills. It is not a strong soil, but is fairly well adapted to the production of corn, oats, and grass. Apples also do well.

Owing to the stiff, tenacious character of the soil and its location on the steep sides of bluffs, the Hobart clay has but little value except as a sheep and cattle pasture.

The Holyoke stony loam occupies rough and mountainous country and is devoted chiefly to pasture, though it is used to some extent for fruit.

The Judson loam is an unimportant type occurring as a colluvial deposit along the foot of the uplands. It is admirably suited to fruit, especially apples. Good crops of corn, wheat, cabbage, and potatoes are raised, but only a small part of the type is at present under cultivation.

The Lexington silt loam is derived from the loess and closely resembles the Memphis silt loam, but the deposit of loess is very thin, the surface is more hilly and broken, and the soil is in places modified by the underlying Lafayette formation. The soil is adapted to corn, cotton, forage crops, vegetables, and strawberries.

The Lynden gravelly loam is covered by a heavy growth of virgin forest. The soil seems especially adapted to the growing of fruits, and much of the cleared land is used for their production. Apples, pears, plums, prunes, etc., do exceeding well and the acreage devoted to orchards is annually increasing. Very fair yields of Irish potatoes have been secured.

The Lynden sandy loam is still covered by a heavy timber growth. When properly cultivated it produces profitable yields of potatoes, fruits, and small fruits. Both clover and timothy have been successful. The soil will grow early vegetables, returning large yields. Field and garden peas produce 50 to 60 bushels per acre. Orchards flourish, particularly the apple, pear, plum, prune, and cherry trees.

Lynden silt loam is well adapted to fruit growing. Large yields of apples, pears, plums, prunes, and cherries are obtained, and the fruit is of fine quality. Raspberries and blackberries are grown to a limited extent and do well; strawberries do exceedingly well. Clover and timothy make good yields of fair quality hay, and Irish potatoes return 200 bushels per acre. Vegetables also prove profitable.

The Lynden fine sandy loam supports a heavy forest of fir and cedar, and a dense undergrowth. Oats yield 50 bushels, and Irish potatoes 200 bushels on an average per acre. Clover and timothy have proved successful on a limited acreage. Cabbage, cauliflower, carrots, pumpkins, garden peas, cucumbers, and other vegetables do well. Canadian field peas yield from 50 to 60 bushels per acre. Many small orchards of various kinds of fruit produce large yields.

The Madison loam frequently has poor drainage, but is a good soil for corn, hay, and truck crops, especially cabbage, tomatoes, and berries.

Madeland includes a small area where fills have been made.

A large proportion of southern Illinois is occupied by Marion silt loam. The type occupies level prarie land and is characterized by hard silty clay subsoil locally known as "hardpan." It is low in organic matter and this combined with the impervious nature of the subsoil causes crops to suffer in wet as well as dry years. Wheat, corn, and grass are the principal crops, but the average yields are considerably lower than upon the black prairie soils. It seems especially well adapted to apples, and many large orchards have been planted. Strawberries also do well.

The Memphis silt loam is one of the most extensive soil types of the United States. It is derived from the deposit of loess which borders the Mississippi throughout a large part of its course. It occupies the uplands and is subject to serious erosion, especially in southern areas. Good yields of cotton, corn, wheat, oats, hay, and potatoes are secured in different localities. In the northern areas the soil is good for fruits and vegetables.

The topography of the Portage sandy loam varies from gently rolling to nearly level, the latter areas being poorly drained. It is adapted to general farm crops, yielding 1½ tons of hay, 100 bushels of potatoes, 30 bushels of corn, 40 bushels of oats, and 10 to 15 bushels of rye per acre. It is also well suited to fruits and vegetables.

The Portage silt loam has been studied in the survey of Portage County, Wis. The type occupies level or slightly undulating areas, is rather poorly drained, and sometimes marshy. It is well adapted to general farm crops, small fruits, and vegetables.

The Portage stony sandy loam has considerable quantities of bowlders, principally of granite, scattered over the surface. The drainage is rather poor and the type is used only for pasture.

The Rhinebeck loam is an easy soil to till and is fairly productive, making good crops of corn, cabbage, and hay. It is of local occurrence and only small areas have been encountered.

Rock outcrop, Rough stony land, Steep broken land, Rough broken land, and Riverwash are mainly nonagricultural land.

The Safford silt loam is associated with the Lexington silt loam and represents a thin deposit of loess over heavy clays of Cretaceous age. The soil is adapted to corn, cotton, wheat, and hay. It has a rolling to hilly topography and washes badly if not properly managed. The surface soil is loose and rather incoherent when dry, and is easily cultivated.

The Scottsburg silt loam is best adapted to tomatoes and other vegetables, to small fruits, and to all early maturing crops. It is low in organic matter, but by the addition of humus and the adoption of suitable crop rotations general farm crops may be made to do well.

The Shelby loam occupies steep slopes adjacent to water courses in northeastern Missouri and southern Iowa. It is much less productive than the Shelby silt loam. It is poorly adapted to wheat and corn and is used almost exclusively for pasture.

The Shelby sand occurs as gently rolling upland and is adapted to truck, small fruit, peaches, and wrapper leaf tobacco. It is very limited in extent and of little agricultural importance.

The Shelby silt loam resembles both the Marshall and Marion silt loam. It differs from the former in having a heavy impervious subsoil and from the latter in the darker color of the surface soil. It occupies the level to gently rolling prairies in northeastern Missouri and southeastern Iowa. The principal crops are hay, corn, oats, and wheat, and the production of apples is also of some importance. The impervious character of the subsoil causes crops to suffer during drought and it is a less desirable soil than the Marshall silt loam.

Whatcom silt loam supports a heavy growth of fir, cedar, and hemlock. It is very productive and a good seed bed is easily formed. It is well adapted to strawberries, Irish potatoes, vegetables, and, of the fruits, to apples, pears, plums, prunes, and cherries. Clover and timothy do well, giving 3 to 4 tons of hay to the acre. Oats and barley produce very fair yields, and peas, cabbage, and garden truck are grown with profit.

The Whatcom stony loam is a rough mountainous soil. Very little of it is cleared and under cultivation, and only a limited acreage is suited for agriculture.

The Wheatland sand is of limited occurrence and has little agricultural value, but is best adapted to pasture and grazing.

The Wheatland sandy loam is an upland soil of good drainage. It is fairly well adapted to wheat, oats, barley, flax, and corn.

The Williams loam may be considered as the semiarid equivalent of the Marshall loam. It occupies a large proportion of the uplands in northwestern North Dakota and northeastern Montana. It is a strong soil and is devoted to wheat and flax and to a lesser extent to oats, barley, rye, and millet. If the moisture conditions were more favorable this soil would be very highly esteemed for agricultural purposes.

The Williams stony loam occurs in the glaciated uplands of the semiarid region. Owing to its rolling topography and stony character it is devoted to pasture.

Area and distribution of the miscellaneous soils of the glacial and loessial regions.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Allis clay	New York	2,304
Allis shale loam	do	2,368
Barnum loam	Minnesota	2,496
Barnum stony loam	do	8,704
Bellingham silt loam	Washington	13,056
Bernardstown loam	Massachusetts	16,064
Bloomfield sandy loam	Indiana	10,944
Cassadaga sand	New York	1,660
Custer loam	Washington	8,128
Custer silt loam	do	8,960
Dover fine sandy loam	New York	8,512
Dover loam	do	28,800
Dutchess stony loam	do	51,776
Dutchess slate loam	do	94,144
Dutchess silt loam	do	117,184
Gloucester loam	do	10,752
Gloucester stony loam	New Hampshire, New York, Rhode Island	413,568
Gloucester stony sandy loam	New Hampshire	67,904
Hobart clay	North Dakota	6,208
Holyoke stony loam	Connecticut, Massachusetts	196,818
Judson loam	Minnesota	3,968
Lexington silt loam	Tennessee	342,272
Lynden gravelly loam	Washington	16,640
Lynden sandy loam	do	30,208
Lynden fine sandy loam	do	5,696
Lynden silt loam	do	16,256
Madison loam	Indiana	2,240
Madeland	New York	1,024
Marion silt loam	Illinois, Missouri	695,040
Memphis silt loam[a]	Illinois, Kentucky, Louisiana, Mississippi, Missouri, Tennessee.	1,643,002

[a] The soil mapped as Memphis silt loam in Posey County, Ind., and Union County, Ky., is Lintonia loam, and mapped as Miami fine sandy loam in St. Clair County, Ill., is the Memphis silt loam.

Area and distribution of the miscellaneous soils of the glacial and loessial regions—Continued.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Portage sandy loam	Wisconsin	9,792
Portage silt loam	do	22,656
Portage stony sandy loam	do	11,392
Rhinebeck loam	New York	1,088
Rock outcrop, Rough stony land, Steep broken land, Rough broken land, Riverwash.[a]	Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, New Hampshire, New York, Vermont, Washington, Wisconsin.	649,920
Safford silt loam	Tennessee	28,544
Scottsburg silt loam	Indiana	37,184
Shelby loam	Missouri	410,368
Shelby sand	do	448
Shelby silt loam	do	402,112
Whatcom stony loam	Washington	28,608
Whatcom silt loam	do	62,592
Wheatland sand	North Dakota	29,504
Wheatland sandy loam	do	16,768
Williams loam	do	272,256
Williams stony loam	do	69,888
Total		5,879,816

[a] Mapped as the Clarksville stony loam in the Dubuque area, Iowa.

GLACIAL LAKE AND RIVER TERRACES.

Another important group of soils occurs in the glacial region, principally as terraces around lakes, or along streams, or as deposits in areas which were formerly covered by water. At the close of the Glacial epoch the lakes in this part of the United States were not only more numerous, but the waters of those which remain reached a higher level and covered areas that are now far above their present shorelines. In some cases several distinct terraces, each one marked by an old shoreline, are easily discernible, and represent successive stages in the lowering of the water level. Their elevation above the lake varies from a few feet to more than 200 feet. The surface of each terrace is usually rolling to level, with a gradual slope toward the lake, but sometimes areas of a rough and broken character occur. The streams which cross these terraces have frequently by their cutting produced deep, steep-sided valleys, especially near the lakes.

The soils of this group vary from typical beach gravels to offshore deposits of heavy clays. The material from which they are derived consists of glacial débris reworked and redeposited in the lakes or along streams. While this glacial material is made up of rocks of widely varying origin, a large proportion of it often consists of the country rock. In the eastern part of the Great Lake region the percentage of sandstone and shale fragments is usually very high, while in the western part more of the igneous rocks are present. This fact, together with differences in drainage conditions, has given rise to several series of soils. The aggregate area of the soils surveyed in this soil province is 5,091,882 acres.

Clyde series.

The soils of the Clyde series consist of reworked glacial material containing a large percentage of organic matter. The surface soil of this series is of a dark-brown to black color, underlain by gray, drab, or mottled yellow subsoils. The dark color of the surface soil, which is the most distinctive characteristic of this series, is due to the accumulation of a large percentage of organic matter under swampy conditions. The soils of the Clyde series may be considered as intermediate between the light-colored Dunkirk soils on the one hand and the Muck and Peat areas on the other. They almost always require drainage, and when this is provided they are very productive.

The loam is the most important member of the series, both in extent and in agricultural value. In Michigan it constitutes the most highly prized soil for sugar beets, giving the most uniform and satisfactory results. When well drained it gives excellent yields of corn, wheat, oats, and hay. Cabbage and canning crops also prove profitable. Much of the type is undeveloped for lack of drainage. Around Racine, Wis., the clay loam has been extensively used for cabbage and also for corn, wheat, and hay. The clay occupies poorly drained areas, and is not much used for agriculture. It is a strong soil, and when drained is well adapted to sugar beets, as well as general farm crops. The fine sandy loam is a very desirable truck soil and is admirably adapted to cabbage, tomatoes, peas, beans, cucumbers, and potatoes. In Michigan it is used to some extent for sugar beets, but is not considered as desirable as the loam or sandy loam. It is not a good peach soil, but where properly drained apples and pears do fairly well. For general farming the sandy loam ranks next to the loam, and this type, together with the stony sandy loam, are devoted largely to this purpose. The gravelly sand and fine sand give fair yields of grain crops, but are best suited to trucking and small fruits, the fine sand being especially adapted to strawberries. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Clyde series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Clyde stony sandy loam	Michigan	8,000
gravelly sand	do	24,656
gravelly sandy loam	Washington	5,952
sand	Michigan	67,400
fine sand	Indiana, New York	61,376
sandy loam	Indiana, Michigan, Washington	111,808
fine sandy loam[a]	Michigan, New York, North Dakota, Wisconsin	141,824
loam	Indiana, Michigan, New York, North Dakota, Washington.	538,796
silt loam	Michigan	3,904
clay loam	Wisconsin	12,224
clay[b]	Indiana, Michigan, New York, North Dakota, Ohio.	235,392
Total		1,211,332

[a] Mapped as Miami sandy loam in the Grand Forks area, North Dakota.
[b] Mapped as Miami black clay loam in Toledo area, Ohio.

Dunkirk series.

The Dunkirk series is an important member of the glacial terrace group of soils. The soils have been formed by the reworking of glacial material derived from limestone, sandstone, and shale. This series embraces light-colored surface soils with drab, gray, and mottled yellow subsoils and occurs principally in the eastern part of the Great Lakes region. The soils are not as productive as those of the Clyde series, but some of them are well adapted to special crops.

The loam is a very important member of the Dunkirk series. It is a good general-purpose soil and is considered fine for fruit, especially apples, pears, plums, and cherries. The color, flavor, and keeping quality of the former two are better than upon either the lighter or heavier soils. The silt loam is easily tilled and produces good yields of general farm crops, besides berries and fruits. Upon the clay loam, clay, and stony clay wheat and grass do well, while near the Lakes grapes are grown with much success. The sandy loam and fine sandy loam are quite extensively used for trucking and small fruits, and in Tompkins County, N. Y., furnish a good example of a case where the special adaptation of a soil to particular crops has been utilized. They are a little light in texture for general farming. Peaches on the fine sandy loam produce a strong, thrifty tree and a good flavored fruit. Grapes are also successfully grown. The fine sand is not suited to general farming, but for early truck and other crops requiring a light sandy soil it has proved valuable. Peaches, apples, and pears are grown, but the trees are usually short lived and subject to disease, while the fruit is of inferior quality. The gravel is of little value except for the production of grapes. The gravelly sandy loam gives moderate yields of ordinary farm crops and should be used as a fruit, potato, and corn soil. The gravelly loam gives large crops of corn and fair crops of hay and oats, while potatoes, beans, and pears also do well. The acreage of the types so far encountered is shown in the table on the following page.

Area and distribution of the soils of the Dunkirk series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Dunkirk stony clay	New York	35,072
shale loam[a]	do	14,592
gravel	New York, Ohio	7,720
gravelly sandy loam[b]	do	87,582
gravelly loam[c]	do	106,816
fine sand	New York	10,944
sandy loam	do	4,480
fine sandy loam[d]	New York, Ohio, Wisconsin	153,290
loam	New York, Ohio	147,712
silt loam[e]	New York	94,272
clay loam[f]	New York, Ohio	127,616
clay[g]	do	140,546
Total		880,592

[a] The soil mapped as Dunkirk shale loam in the Westfield area, New York, is the Dekalb clay.

[b] Mapped as Dunkirk gravelly loam in the Ashtabula area, Ohio, and Westfield area, New York.

[c] Mapped as Miami gravelly loam in the Big Flats and Syracuse areas, New York.

[d] Mapped as Miami fine sandy loam in the Lyons and Syracuse areas, New York. Mapped as Dunkirk sandy loam in the Ashtabula area, Ohio, and Westfield area, New York.

[e] Mapped as Miami silt loam in the Syracuse area, New York.

[f] Mapped as Miami clay loam in the Toledo area, Ohio.

[g] The areas mapped as Dunkirk clay in the Lyons and Syracuse areas, New York, are Alloway clay.

Fargo series.

The Fargo series occurs throughout the Red River Valley and in other old glacial lake beds in the same region. The soils have been formed by the reworking of glacial material and its deposition in glacial lakes. The soils are very black in color and contain a very large percentage of organic matter, in some cases enough to make the soil slightly mucky. There is also present, especially in the subsoil, a large percentage of lime. They rank among the most productive soils in the country.

The clay loam is the most extensive and one of the strongest types of soil in the Red River Valley. The surface is very level and artificial drainage is necessary, but when this is provided the soil is well adapted to wheat, oats, barley, and flax. Similar experiments with clover and alfalfa demonstrate that they can be grown successfully. About the same crops are grown upon the fine sandy loam as upon the clay loam, but owing to naturally better drainage the yields are more certain. Vegetables, which do well, are produced to a limited extent for local markets. Timothy is grown mainly for hay. The silt loam is probably the most desirable soil in the valley and is well suited to wheat, oats, barley, and flax, giving excellent yields of all these crops. This type has contributed most to the fame of the Red River Valley as a wheat-growing country. Vegetables and garden truck are grown with excellent results. The loam, naturally poorly drained, owing to its low, flat topography, is used largely for hay. It is a strong soil and where well drained produces good wheat, flax, and oats. The clay is a very heavy soil, locally called "gumbo." It is regarded as one of the most productive of soils, but it is rather difficult to get the seed in early enough in the spring and to keep the soil from baking after rains. Under the present imperfect condition of drainage these lands are held in low esteem for general farming. When seeded with brome grass or covered with natural prairie grass they are excellent for hay and pasture. A very large proportion of the sandy types is yet unbroken and utilized chiefly for the production of wild hay. When drained they are good soils for potatoes, small fruits, and corn. Where earliness of maturity is so important as in this latitude, the light texture makes them better suited to the latter crops than the heavier soils. Wheat, flax, and wild hay are the chief crops at present.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Fargo series.

Soil names.	States in which each type has been found.	Total area.
		Acres.
Fargo sand	North Dakota	22,016
fine sand	do	19,904
loam	do	20,800
fine sandy loam	Minnesota, North Dakota	133,504
silt loam	do	27,072
clay loam	do	344,576
clay	do	70,336
Total		638,208

Hudson series.

The Hudson series consists of light-brown to yellowish-brown soils, underlain by drab to yellowish subsoils. The latter are generally lighter in texture than the soils of the Vergennes series. They occur as glacial lake terraces, composed principally of wash from glaciated slate uplands, and are generally quite desirable soils.

The sandy loam is easy to work, but very little is cultivated. It is particularly well adapted to truck and small fruits, and produces also fair yields of the general farm crops. The fine sandy loam is also well suited to trucking and in favorable localities is highly esteemed for fruits and vegetables. The gravelly subsoil of the loam gives it good drainage, and it grows good thrifty apples and produces small fruits, truck crops, especially heavy truck, such as potatoes, tomatoes, and root crops. Away from the immediate vicinity of the villages mixed farming is practiced, dairying being carried on in connection with general farming and fruit growing. The heavy character and impervious nature of the subsoil make the clay loam cold and wet. It is therefore not very desirable for general farming, although well suited to grass. The areas of the several types so far encountered are as follows:

Area and distribution of the soils of the Hudson series.

Soil name.	State in which each type has been found	Total area.
		Acres.
Hudson clay loam	New York	9,984
fine sandy loam	do	6,400
loam	do	3,904
sandy loam	do	1,856
Total		22,144

Merrimac series.

The Merrimac series is found almost entirely in the New England States and constitutes the glacial terraces which occur along nearly all the streams of this section. The material consists principally of crystalline rocks which were ground up by the ice, reworked by water, and deposited during the close of the glacial period. The soils are brown in color and are underlain by sand and gravel.

In New England and eastern New York there occurs along the streams on high terraces a series of soils to which the name Merrimac has been given. From their composition and structure they are usually leachy soils, and this is specially the case with the coarser soils. The coarse sand and gravelly sandy loam are of low crop producing value, but with fertilization they produce garden crops. The sand, though not cultivated to any extent, is a soil that in its locality would be valuable for trucking. The gravelly loam has a wider crop adaptation, producing the general farm crops and in eastern New York apples. The fruit colors especially well, but matures so early that the keeping quality is not as good as fruit produced on later soils. The loam and sandy loam are strong grass and corn soils. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Merrimac series.

Soil names.	States in which each type has been found.	Total area.
		Acres.
Merrimac coarse sand[a]	Connecticut, Massachusetts, New Hampshire, Rhode Island.	112,136
coarse sandy loam[b]	Connecticut, Massachusetts, Rhode Island	110,720
gravelly sandy loam	Connecticut, Massachusetts, New Hampshire, New York.	119,124
gravelly loam	New York	41,216
sandy loam	Connecticut, Massachusetts	95,304
sand	New Hampshire	26,560
loam	New York	1,600
Total		506,660

[a] Mapped as Norfolk coarse sand in Rhode Island.

[b] Mapped as Norfolk coarse sandy loam in the Connecticut Valley area, Connecticut-Massachusetts.

Sioux series.

The Sioux series comprises the dark-brown to black terrace soils characterized and distinguished from the Wabash series by a bed of gravel usually within 3 feet of the surface. This gravel bed has a very marked effect upon the drainage of the soils and causes crops to suffer in times of drought, except in areas where the gravel is several feet below the surface. This series occurs as terraces along streams, and is practically confined to the glacial regions.

The sandy loam is well suited to the production of early short-seasoned crops. The fine sandy loam is less droughty than the sandy loam, and produces good yields of corn, wheat, oats, barley, alfalfa, and sugar beets. The sand and gravelly sandy loam give uncertain yields on account of excessive drainage. The loam is admirably adapted to the growing of crops for canning purposes, although largely used for general farming. The silt loam is an exceedingly fertile soil, very highly esteemed for corn and small grain. The clay is also a strong soil for general farming. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Sioux series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Sioux gravelly loam	North Dakota	30,400
gravelly sandy loam	Minnesota	24,448
sand	Wisconsin	19,520
sandy loam[a]	Illinois, Indiana, Iowa, Missouri, Nebraska, South Dakota, Wisconsin.	198,848
fine sandy loam	Nebraska, North Dakota	65,984
loam[b]	Illinois, Indiana, North Dakota	49,152
silt loam	Illinois, Indiana, Wisconsin	32,826
clay	North Dakota	2,432
Total		423,610

[a] Mapped as Miami loam in the Janesville area, Wisconsin.
[b] Mapped as Miami loam in Tazewell County, Ill.

Superior series.

Another member of the glacial lake group of soils is found around Lake Superior. The material here consists of a red clay, over which in some places sands and sandy loams have later been deposited or washed from higher lying areas, giving rise to soils of a light and more sandy character. There has thus been formed the Superior series of soils, characterized by the red color of the subsoils.

The sandy loam of the Superior series is a warm soil, easily tilled, and adapted to clover, timothy, potatoes, and small fruits. The topography of the silt loam is so uneven as to make this type of low agricultural value. The clay is a heavy soil, being rather difficult to cultivate, but yields good crops of timothy and clover, as well as potatoes, peas, and beets. None of the soils of the series have been extensively developed.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Superior series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Superior sandy loam	Wisconsin	14,208
silt loam	Minnesota	16,192
clay	Michigan, Minnesota, Wisconsin	198,784
Total		229,184

Vergennes series.

The Vergennes series occurs on the terraces surrounding Lake Champlain. It consists of deep-water sediments known as the Champlain clays, deposited in postglacial times over glacial drift during a period of submergence. Since the uplift these clays have been more or less modified by stream action and colluvial wash from soils of the surrounding highlands derived from the underlying geological formations, usually sandstone, shale, and limestone, and in limited areas by wash from glacial drift soils. The series is characterized by brown, yellowish, or gray soils, underlain by drab to blue or light-gray clay subsoils at varying depths. The surface is level to gently rolling, and for the most part artificial drainage is necessary.

The clay is the most extensive, as well as the most important, of the Vergennes soils. It is a heavy soil—one which requires careful and painstaking cultivation to secure the best results. Its heavy texture makes it admirably adapted to the production of hay, and this constitutes the leading crop. It is not an ideal corn soil, but profitable yields of this grain, as well as of oats and barley, are secured. The black clay requires drainage, and were this done it would be the best corn soil of this section. Good yields of hay are cut from the better drained portions, while the more poorly drained portions are used only for pasturage. The best apple orchards in the Champlain Valley are found upon this type and the fruit produced is of high quality. Soils better adapted to tilled crops militate against the extensive cultivation of this type, most of which is used as pasture or woodland. Certain of the more easily tilled portions are highly esteemed for potatoes. The fine sand is best adapted to truck crops and small fruits, though corn, oats, and hay are grown with fair success; corn, clover, and late truck do well on the sandy loam, while the loam is desirable for corn, hay, oats, and barley. The gravelly loam is well adapted to potatoes. The acreage of the types so far encountered is given in the table on page 161.

Area and distribution of the soils of the Vergennes series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Vergennes stony loam	New York, Vermont	17,024
gravelly loam	do	3,968
fine sand	do	8,384
sandy loam	do	2,112
loam	do	4,352
black clay	Vermont	3,584
clay	New York, Vermont	129,984
Total		169,408

Miscellaneous soils of the glacial lake and river terraces.

The Bearden loam is closely related to the Sioux loam, but differs from it in that the gravel and sand are much farther below the surface. It is fairly level in topography, and nearly all of it is sufficiently well drained to produce good crops. At present the soil is devoted chiefly to small grains, flax, and wild hay, of which good yields are secured.

The Benoit loam is closely associated with the fine sandy loam, and like this type occurs as broad, shallow, poorly drained depressions between old beach lines. A few of the better drained areas are cultivated, but the soil as a whole is so poorly drained that it is used mainly for pasture land or hay meadows.

The Benoit fine sandy loam occupies low, basinlike depressions which occur between or adjacent to old beach lines. A large part of it is poorly drained and only a very small part is under cultivation. The greater proportion is used for hay meadows and as pasture.

On account of its compact nature and poor underdrainage the Elmwood loam, which occupies level terraces along the Connecticut River, has very little agricultural value at present.

The Enfield sandy loam represents the overlapping of sandy glacial lake deposits upon the glacial till. Some tobacco of fair quality is produced and medium yields of truck and grain are secured, but the soil is not well suited to the production of grass. The type is not of much agricultural importance.

The Marco clay loam is well adapted to grass, and heavy crops of clover and timothy are obtained. The type is rather poorly drained, but when drainage is provided it is a strong, fertile soil.

Owing to the level, stony nature of the Lockport clay the greater part of the type is devoted to pasture. It is best suited to grass, which fact has been generally recognized.

The McLeod sand consists of low, rounded dunes and ridges scattered over comparatively level sandy plains forming the bed of glacial Lake Agassiz. A large part of the type is used for pasture. Wheat, oats, barley, and flax are grown to a limited extent, but the yields are light.

The Manchester sandy loam is naturally a fertile soil, but the porous character of the subsoil renders it subject to drought. It is well adapted to peaches and fairly well to corn.

The Mankato loam is closely associated with the Mankato sandy loam and occupies a similar topographic position. The presence of the underlying rock near the surface causes it to suffer from drought during dry seasons. With favorable rainfall good crops of corn and wheat are secured.

The Mankato sand occurs as terraces along the Blue Earth River in Minnesota. On account of its good natural drainage the soil warms up early in the spring, making it well suited to the production of early vegetable and market-garden crops.

The Mankato sandy loam occurs as a river terrace, and the soil is underlain by rock at an average depth of 15 inches. This makes the type subject to drought. In seasons of heavy rainfall good crops are secured. Where the sand is deepest it is quite well adapted to the production of early vegetables.

The Marco fine sandy loam occupies nearly level to rolling areas and consists of old alluvial deposits modified by wind action. Wheat and corn are successfully grown and clover does exceptionally well. The slightly elevated portions of the type are very desirable sites for small fruit and truck gardens.

Muck and Peat are composed largely of organic matter in various stages of decay, the Muck representing an advanced stage of change in Peat areas. These soils are highly valued for their adaptation to special crops, such as celery, onions, peppermint, and cabbage.

The Newton fine sand occurs in level, poorly drained, marshy areas, and its chief use is for pasture.

The Podunk fine sandy loam occurs as terraces along the Connecticut and other rivers in New England. It is considered the most desirable soil in the Connecticut Valley for the production of the broadleaf tobacco. Corn and potatoes do well on this type, and it is regarded as a strong, safe, and productive soil.

The Podunk silt loam occupies level terraces along the streams throughout New England. It is best adapted to grass crops and gives large yields of hay.

The Saginaw sandy loam occupies an intermediate position between the Clyde sand and the Clyde loam. When properly drained the soil is fairly well adapted to truck, sugar beets, and corn, as well as to general crops.

Sandhill and Dunesand are deep sands of little agricultural value.

The Saugatuck sand is characterized by bands of sand cemented together by iron, forming a crust from a fraction of an inch to one or more inches in thickness. The type occupies slightly depressed areas and is best adapted to truck, peaches, and small fruits. Grain also does fairly well.

The Snohomish fine sandy loam occupies level to gently rolling river terraces in the vicinity of Puget Sound. The type is best adapted to late truck crops for canning purposes, and fruit also does well.

The Snohomish sand has a flat and fairly level surface, rising with a gentle incline from near sea level toward the inland. While the drainage is generally adequate on account of the easy fall and open texture, the soil is subject to drought. The soil is too light for general farming, but under suitable conditions might be utilized for the growing of early truck. It is also well adapted to early potatoes.

The Snohomish silt loam occupies level or gently rolling river terraces and is a good soil for general farming, as well as for the production of tree fruits.

On account of its close texture and poor drainage, the Suffield clay, found only in Connecticut and Massachusetts, has no value except as pasture land.

Swamp and Marsh consist of areas covered with water the greater part of the year and unfit for agriculture, except where drained and protected from tidal or fluvial overflow. When reclaimed much of this land will become very productive.

The Tonawanda loam is closely associated with the Dunkirk loam, but differs from it in having a lighter subsoil. The chief crops grown are corn, oats, hay, and potatoes, and during favorable seasons fair yields are produced.

The soil of the Warners loam, which is derived from marl, consists of 10 inches of mellow brown loam containing many calcareous nodules and a considerable proportion of marl. The subsoil is a gray or white marl, silty in character and of soft, unctuous feel, containing thin beds of muck at varying depths. The type produces good crops of corn and grass.

The Williston gravelly sandy loam occurs as terraces along streams in the semiarid glacial region. The gravelly character of the subsoil makes it subject to drought, but when moisture conditions are favorable it gives good crops of wheat, flax, and rye.

The Williston sandy loam is closely related to the type just described. It occurs as glacial terraces in the semiarid region. In seasons of average rainfall good crops of wheat and flax are secured.

The acreage of the types so far encountered is as follows:

Miscellaneous soils of the glacial lake and river terraces.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Bearden loam	North Dakota	3,584
Benoit loam	Minnesota	31,360
Benoit fine sandy loam	do	4,032
Elmwood loam	Connecticut, Massachusetts, Michigan	22,688
Enfield sandy loam	Connecticut, Massachusetts	46,462
Lockport clay	New York	6,656
McLeod sand	Minnesota, North Dakota	38,016
Manchester sandy loam	Connecticut, Massachusetts	44,160
Mankato loam	Minnesota	1,600
Mankato sand	do	4,032
Mankato sandy loam	do	2,816
Marco clay loam	Indiana	3,200
Marco fine sandy loam	do	3,392
Muck and Peat	Illinois, Indiana, Iowa, Michigan, New York, North Dakota, Ohio, Vermont, Washington, Wisconsin.	532,842
Newton fine sand	Indiana	5,888
Podunk fine sandy loam	Connecticut, Massachusetts, New Hampshire, New York.	30,404
Podunk silt loam	New Hampshire	960
Saginaw sandy loam	Michigan	14,272
Sandhill, Dunesand, and Coastal beach.	Michigan, Minnesota, North Dakota, Rhode Island, Wisconsin.	26,234
Saugatuck sand	Michigan	24,120
Snohomish fine sandy loam	Washington	9,728
Snohomish sand	do	21,504
Snohomish silt loam	do	16,192
Suffield clay	Connecticut, Massachusetts	23,610
Swamp, Tidal swamp and marsh	Indiana, Michigan, New York, Rhode Island, Vermont, Washington.	62,080
Tonawanda loam	New York	15,168
Warners loam	do	128
Williston gravelly sandy loam	North Dakota	12,352
Williston sandy loam	do	3,584
Total		1,010,744

RESIDUAL SOILS OF THE WESTERN PRAIRIE REGION.

This region consists of the nonglacial part of the prairie plains bounded on the north by the Missouri River, the southern limit of glaciers, and extending southward through Texas to the Rio Grande. On the west it merges into the Plateau region at very near the 2,000-foot contour, and on the east is limited by the Gulf Coastal Plain and the Ozark Plateau. Its surface is gently rolling, with occasional low hills, and is cut by numerous stream channels. The rocks are of Carboniferous age and consist of sandstones, shales, and limestones more or less interbedded. These rocks give rise to three series of soils, viz, Oswego, Crawford, and Vernon, together with a number of miscellaneous soils. In Kansas and Texas these soils are in some instances more or less modified by the admixture of gravel and sand from Tertiary deposits brought down from the higher areas farther west occupied by crystalline rocks.

The aggregate area of the soils surveyed in this province is 1,825,850 acres.

Crawford series.

This series includes residual limestone soils of the prairie regions, characterized by dark-brown to reddish-brown surface soils and reddish-brown to red subsoils. While derived from limestones, these soils usually contain only a small percentage of lime, differing very materially in this respect from the soils of the Houston series, occurring in the Cretaceous black prairies of the Coastal Plain. They are productive and well adapted to general farming.

The gravelly loam occurs in small bodies on ridges and hilltops, and on account of the gravelly surface and the too freely drained, leachy nature of the subsoil this type is too droughty for agricultural purposes, except in occasional wet seasons, when corn gives fair yields. The type is on the whole best adapted to stock raising, though small fruits may be found to do well in favored locations. The Crawford stony clay is a shallow, excessively stony soil, in general too rough and broken in topography for crops requiring much cultivation. It is well watered by numerous small streams, however, and produces a good growth of grass, making it a good grazing type for cattle, sheep, and goats. Grapes and small fruits do well. The texture of the loam makes it easy to cultivate, and it can be worked very shortly after rain without impairing the naturally good mechanical condition. The type is well suited to the cultivation of cotton, corn, and fruits and also produces very fair yields of wheat and oats. Several small orchards of peaches and plums produce very profitable crops, and fruit growing bids fair to become an important industry. Vegetables are successfully grown for home use and on a small scale for local markets. The silt loam occupies level to rolling prairies, and is well drained, with the exception of level and depressed areas. This soil is best adapted to corn; but all general farm crops, as well as fruits and vegetables, do well on this type. It is a strong, fertile soil well adapted to general farming. The clay is a heavier soil and more difficult to cultivate than the silt loam. It is, however, a strong soil, well adapted to wheat; while cotton, corn, alfalfa, clover, and timothy do well. The silt clay is probably the most valuable soil of the series and nearly all of it is under cultivation. It has been found along the foot of the escarpment extending from Austin to San Antonio, Tex. It is the most desirable truck soil in this section, and considerable areas are irrigated and planted to onions, which constitute the principal crop on irrigated areas. It is also an excellent soil for general farming and produces large yields of corn, cotton, oats, peanuts, and potatoes. Alfalfa also does well, and as many as nine cuttings, with an average of three-fourths of a ton per acre for each cutting, have been secured on an irrigated field.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Crawford series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Crawford stony clay	Texas	119,104
gravelly loam	Kansas	5,165
loam	Texas	6,784
silt loam	Kansas	211,559
silt clay	Texas	18,048
clay	Kansas, Texas	180,864
Total		541,524

Oswego series.

The Oswego series includes the light-colored soils of the prairie region formed from the weathering of interbedded layers of sandstone and shale, as distinguished from the Crawford series, which is derived from limestones. The surface soils are light to dark gray in color, while the subsoils are dark drab to yellow. The soils of the Oswego series are less productive than those of the Crawford series.

The Oswego fine sandy loam is of a light, sandy character and warms up early in the spring, permitting the planting of crops considerably earlier than upon the soils of heavier texture. In relatively wet seasons it is a good general-purpose soil, though yields are only fair. It is probably best adapted to corn, oats, and potatoes, being too light for wheat. Where located near enough to markets truck and fruit crops could be profitably grown. The silt loam of this series is a well-drained, moderately fertile soil, subject in some sections of Kansas to considerable erosion. On account of the close texture of the soil and heavy character of the subsoil it requires careful cultivation to preserve proper tilth. The areas which have been developed show the soil to be best adapted to wheat, with oats and corn second in importance.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Oswego series.

Soil name.	State in which each type has been found.	Total area.
		Acres.
Oswego fine sandy loam	Kansas	25,293
silt loam[a]	do	462,848
Total		488,141

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[a] The soil mapped as Oswego silt loam in the Parsons area, Kansas, is the Neosho silt loam.

Vernon series.

The Vernon series includes the upland sands, loams, and clays derived from the weathering of the Permian Red Beds. The surface soils are gray and brown, while the subsoils are brown to red. This series occurs in the prairie regions of northern Texas and in Oklahoma. The soils are productive and well adapted to general farm crops.

The Vernon silt loam is the most important of the Vernon soils, both in extent and in agricultural importance. It occupies level and gently rolling prairie uplands and is a fine soil for general farming. A very large percentage of it is under cultivation, while the remainder is in prairie grasses, which are cut for hay. Wheat, oats, and corn are the crops most extensively grown. Cotton makes a good growth, but matures late, yielding from one-half bale to 1 bale per acre. Alfalfa and castor beans are also raised on this soil. Another important agricultural type of this series is the fine sandy loam. Oats, wheat, Kafir corn, and sorghum are among the principal crops. Cotton yields from one-third to three-fourths of a bale per acre. Peaches are grown commercially on this soil, and where properly located and cared for the orchards do excellently. In a limited way grapes are found. This soil also makes fine pasture. Owing to the lightness of the sand of this series, it is difficult to get a stand of any crop, and therefore farming on this soil should not be attempted to any great extent. Cotton and corn are the principal crops grown, though apples and peaches also do well when the trees once get started. The fine sand type is undesirable for agricultural purposes and cotton and corn yield only small crops. Peaches are grown in a limited way. The forested portions are used for pasture. The Vernon sandy loam is devoted to a variety of crops. Corn yields from 30 to 40 bushels per acre, oats from 30 to 60 bushels, Kafir corn from 20 to 40 bushels, and cotton from one-half bale to 1 bale per acre. The soil is too sandy to give satisfactory results to wheat except during favorable seasons. It is an excellent peach soil. This type is also good for truck, but at present only a small area is used for this purpose.

The greater part of the clay type of the Vernon series is used for pasture. Wheat, oats, and corn are the principal crops. This soil would be greatly improved by planting to Bermuda grass, which would afford good pasture for eight or nine months.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Vernon series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Vernon sand	Oklahoma, Texas	68,224
fine sand	Oklahoma	44,928
sandy loam	Oklahoma, Texas	40,576
fine sandy loam	do	167,296
silt loam[a]	do	190,464
clay	do	31,808
Total		543,296

[a] The soil mapped as Vernon silt loam in the Vernon area, Texas, is the Miller silt loam.

Miscellaneous residual soils of the western prairie region.

The Derby loam is a good soil for general agriculture. The chief crops are corn and wheat, the average yields being about 25 and 18 bushels, respectively.

The Gasconade silt loam is associated with the Clarksville silt loam, but is a more productive soil. Corn, wheat, timothy, and clover do well.

Rock outcrop, Rough stony land, Steep broken land, Rough broken land, and Riverwash are mainly nonagricultural land.

The Sedgwick black clay loam occupies flat or depressed areas in the upland prairies and is poorly drained. It is generally used only for pasture to wheat and corn.

The area of granite near Tishomingo, Okla., gives rise to the Tishomingo gravelly sandy loam. The more level areas form prairies covered with a growth of wild grasses, which furnish good grazing and a fair grade of wild hay. Corn and cotton do fairly well in a favorable season. Near the streams the type is covered with a scrub growth of timber, mostly oak, and is of low agricultural value.

The acreage of the types so far encountered is as follows:

Area and distribution of the miscellaneous soils of the western prairie region.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Derby loam	Kansas	20,416
Gasconade silt loam	Arkansas Missouri	16,320
Rock outcrop, Rough stony land[a]	Kansas Oklahoma, Texas	180,889
Sedgwick black clay loam	Kansas	5,568
Tishomingo gravelly sandy loam	Oklahoma	29,696
Total		252,889

[a] Mapped as Clarksville stony loam in Wichita area, Kansas.

GREAT BASIN.

With the exception of one soil type recognized in the Laramie area, Wyoming, the soils in this group, so far as mapped, are confined to the Great Interior Basin region. They are derived from a great variety of rocks, and consist of colluvial soil of the mountain slopes, deep lacustrine and shore deposits of the Bonneville period, and of recent stream-valley sediments and river-delta deposits.

When not situated above or outside the limits of irrigation, or rendered unfit for cultivation by accumulation of alkali or seepage waters, they are of great agricultural importance, and are devoted mainly to the production of grains, sugar beets, alfalfa, stone or other tree fruits, and vegetables.

The aggregate area of the soils surveyed in this province is 1,005,600 acres.

Bingham series.

This series covers lower mountain slopes, upper valley slopes, and valley plains. It consists of colluvial mountain wash or of old alluvial deposits of torrential or intermittent streams, delta-cone deposits, or of a mixture of these materials. The soils are usually gravelly and generally treeless, except in the immediate vicinity of stream courses. The more elevated areas are frequently rough and hilly and marked by the presence of rock outcrop and bowlders. They are frequently cut by washes or intermittent stream channels and are well drained, except in the lower lying areas occupying depressions.

These soils are derived principally from eruptive, early sedimentary, and altered sedimentary rocks of all ages, and modified particularly by material derived from limestone, granites, shales, slates, etc. They occur as irregular and frequently extensive bodies, often lying above the limits of irrigation. When capable of irrigation, the soils are often well adapted to peaches and other fruits.

Of this series the gravelly loam has the highest agricultural value. It is chiefly adapted to fruit, such as apples, peaches, pears, cherries, plums, and apricots, and in some localities to raspberries and strawberries. It is also suitable for growing wheat, alfalfa, and grains, and in the vicinity of Salt Lake, Utah, in seasons of good rainfall, 20 bushels of wheat to the acre have been produced. In some localities this type is dry-farmed to wheat with good results. Vegetables may be grown on the gravelly loam, but not with the success of the other crops mentioned. The stony loam type of this series is situated above irrigation canals, and the soil is so filled with stones and bowlders that it is of little agricultural value. If, however, this land could be irrigated it would produce good fruits. It is at present used to some extent for mountain pasture. The loam needs irrigation, and when free from excessive amounts of alkali produces good alfalfa and grains. The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Bingham series.

Soil name.	State in which each type has been found.	Total area.
		Acres.
Bingham stony loam	Utah	62,222
gravelly loam [a]	do	132,112
loam	do	12,100
Total		206,434

[a] Mapped as Maricopa gravelly loam in the Provo area, Utah.

Jordan series.

The Jordan series consists of old stream sediments, probably deposited to a large extent in the waters of former lakes and modified by later shore and stream deposits. It thus consists of a mixture of stream and lacustrine sediments and occurs upon low, level or sloping valley plains covering the bed, benches, and shores of ancient Lake Bonneville. The soils are not subject to present extensive stream modification, and are treeless, except in the vicinity of streams or lakes. With the exception of the lower lying bodies the soils are usually well drained. The material is derived from a great variety of rocks of all ages, consisting of lavas, sandstones, shales, limestones, slates, quartzites, granites, etc. The soils occur as irregular and frequently as extensive areas, with the exception of the members of lighter texture, and are dark in color and agriculturally important, except where poorly drained and alkaline. They are generally devoted to grain, alfalfa, fruits, and truck crops.

Of the Jordan series, the sand is the leading truck and fruit soil, devoted extensively to the production of tomatoes, peaches, plums, etc. It is somewhat leachy in character, necessitating frequent irrigation, and is sometimes injured by the rise of the water table when not naturally well drained. The loam is the leading sugar-beet producing soil of this series, being followed by the clay loam in adaptation to this crop. These two soil types are adapted to irrigation and are easily cultivated, but sometimes subject to injury from accumulation of alkali or seepage water. The fine sand usually occurs in wind-blown areas and is relatively unimportant. The clay is often poorly drained and alkaline, but when well drained is adapted to alfalfa and grains.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Jordan series.

Soil name.	State in which each type has been found.	Total area.
		Acres.
Jordan sand[a]	Utah	82,168
fine sand[b]	do	4,920
fine sandy loam	do	48,620
loam[c]	do	95,700
clay loam	do	161,280
clay[d]	do	6,528
Total		349,216

[a] Mapped as Fresno sand in the Provo area and Weber County, Utah.

[b] Mapped as Jordan sand in Weber County and the Salt Lake area, Utah.

[c] The soil mapped as Jordan loam in the Provo and Bear River areas, Utah, is Jordan clay loam.

[d] The soil mapped as Jordan clay in the Salt Lake area, Utah, is Salt Lake clay loam.

Malade series.

This series occurs along valley troughs and in the vicinity of river flood plains, and consists of stream sediments of recent date or in process of formation. The soils occupy low or slightly elevated valley plains of smooth, nearly level surface, frequently marked by the presence of stream channels or sloughs. They are derived mainly from eruptive, early sedimentary, and altered sedimentary rocks, and occur as small narrow to broad, extensive areas. The soils are generally dark in color and are underlain by light-colored sands or sandy loams or by heavy red subsoils. The heavy members are compact. The areas are generally well drained.

The sandy loam is usually well drained and free from alkali, making a good soil for general farming. It is one of the best soils for sugar beets when under irrigation. The fine sand is also suitable for general farming purposes and for sugar beets when irrigated. Alfalfa forms the principal crop of the fine sandy loam, and in some localities orchards do well. It is also adapted to sugar beets. The loam, when free from alkali, produces fine sugar beets and grain, and when the water is not too near the surface it is suitable for fruits and alfalfa.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Malade series.

Soil name.	State in which each type has been found.	Total area.
		Acres.
Malade fine sand	Utah	6,080
sandy loam	do	3,264
fine sandy loam	do	10,112
loam	do	16,640
Total		36,096

Redfield series.

The Redfield series extends from mountain bases across plateau-like plains, upper valley slopes, and sloping plains of narrow valleys to nearly level plains adjacent to the valley trough. The soils of this series are formed of colluvial mountain wash, or sometimes of residual material, mingled with alluvial delta cone deposits of intermittent or torrential streams. They are generally treeless, often gravelly, sometimes marked by rock outcrop, and frequently cut by washes and intermittent stream channels. The soils are derived primarily from red sandstone, modified in places by an admixture of material derived from shales, slates, eruptive rocks, etc., and are typically of vermilion or bright red color. They generally occur as extensive areas. The lower lying and heavier members of the series are often poorly drained and alkaline.

The soils of this series need irrigation to produce any crops. The fine sandy loam type when reclaimed from alkali will produce good crops of alfalfa and grains. Those portions of this type that are above the present system of canals are free from injurious amounts of alkali. The loam of this series is below the canals, and much of it is wet and contains an excess of alkali. In its virgin state it is covered with grease wood. Some portions of this loam are good for general farming. The clay loam of the Redfield series is very stiff and therefore difficult to free from alkali. When partly reclaimed it will produce salt grasses, and it sometimes makes good pasture land. As a whole, the series has not been much developed.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Redfield series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Redfield fine sandy loam	Utah, Wyoming	86,824
loam	Utah	14,100
clay loam	do	3,800
Total		104,724

Salt Lake series.

The Salt Lake series consists of lacustrine sediments and material derived from stream deltas. The soils of this series occur upon low, level plains, marking the site of recent lake bottoms. They are generally barren, deficient in drainage, and heavily impregnated with alkali salts. They are derived from eruptive, sedimentary, and altered rocks of various ages and are without gravel. They cover extensive areas, and are usually dark in color.

The soils of the Salt Lake series are in general not adapted to the production of crops at present, owing to their low-lying position, imperfect drainage, and high content of alkali salts.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Salt Lake series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Salt Lake sand	Utah	2,292
sandy loam	do	51,308
loam	do	19,968
clay loam [a]	do	89,166
Total		162,734

[a] Mapped as Jordan clay in the Salt Lake area, Utah.

Miscellaneous soils of the Great Basin.

The Elsinore sand and Elsinore fine sandy loam are generally leachy and porous or poorly drained and alkaline.

Gypsum, derived from gypsum deposits, is of very little agricultural value.

Meadow, low-lying, flat, and poorly drained land of variable texture. Frequently of some value for grass and pasturage, and in the South for corn after subsidence of floods. Much more of it can be reclaimed by simple methods of drainage, and when this is done excellent results can be secured from a variety of crops.

Rock outcrop, Rough stony land, Steep broken land, Rough broken land, and Riverwash are mainly nonagricultural land.

The Weber fine sandy loam is the most important soil of this group, being devoted to the production of grains, sugar beets, alfalfa, and deciduous fruits when irrigable and free from alkali.

The acreage of the types so far encountered is as follows:

Area and distribution of the miscellaneous soils of the Great Basin.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Elsinore fine sandy loam	Utah	7,800
Elsinore sand	do	1,900
Gypsum	Wyoming	2,304
Meadow	Utah	25,188
Rock outcrop, Rough stony land, Steep broken land, Rough broken land, and Riverwash.	do	1,300
Weber fine sandy loam [a]	do	107,904
Total		146,396

[a] Mapped as Fresno fine sandy loam in the Bear River area and Weber County, Utah.

NORTHWESTERN INTERMOUNTAIN REGION.

The most extensive and uniform soil types of this region consist of residual materials overlying and derived from extensive basaltic lava plains and in some cases from granitic rocks or of ancient lacustrine sediments or extensive lake beds now more or less modified by erosion or æolian agencies. Owing to erosion by streams and to movements of the earth's crust, these soils now generally occupy more or less elevated sloping or rolling plains. About the margins of the lacustrine or residual deposits they are covered by sloping plains and fans of colluvial wash from the adjacent mountain borders, while in the vicinity of the larger streams, which have carved and terraced the lacustrine beds and residual soils, occur other series of recent alluvial stream sediments derived from reworked materials of the lake beds or from the weathered products of the mountains. It is the soils of this region that constitute a large portion of the great grain-producing lands of the Northwest.

The aggregate area of the soils surveyed in this province is 1,455,428 acres.

Bridger series.

The soils constituting this series occur upon mountain foot-slopes, lower foothills, high or sloping plains, mesa lands, and alluvial fans or fan deltas, and consist of colluvial mountain waste mixed with stream delta-cone deposits. The higher lying areas are often rough and hilly, marked by rock outcrop, bowlders, or glacial morainic débris, and deeply cut by stream channels. The soils are generally treeless or sparsely timbered, except in the vicinity of streams. The members of this series are derived from granitic rocks, gneiss, basaltic, andesitic, or other volcanic rocks, with an admixture of materials derived from sedimentary rocks, and occupy small irregular to broad extensive areas. The soils are generally of dark color, and are underlain by sticky subsoils of light-gray or yellow color. The soils and subsoils are generally gravelly, the gravel varying from fine angular chips to large, well-rounded or angular blocks and cobbles.

The soils of the Bridger series are usually retentive of moisture and extensively utilized for the production of dry-farmed grains, consisting of wheat, oats, and barley, although irrigation is sometimes necessary for the production of these crops. Under irrigation, alfalfa, clover, timothy, and hardy fruits are also produced to a limited extent.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Bridger series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Bridger gravelly loam[a]	Montana, Oregon	29,760
loam[b]	Oregon	30,784
clay loam	Montana	1,472
Total		62,016

[a] Mapped as Maricopa gravelly loam in the Baker City area, Oregon.
[b] Mapped as Maricopa sandy loam in the Baker City area, Oregon.

Gallatin series.

The Gallatin series occupies lower, nearly level, or slightly sloping stream terraces or alluvial river-valley plains adjacent to stream channels. The soils of this series are formed by recent flood-plain deposits, with an admixture of reworked lake sediments. They are underlain by beds of gravel and cobbles, at depths varying from a few inches to several feet, sometimes partially cemented by lime. The areas are often marked by shallow beds or channels of meandering streams, and are frequently timbered or covered with willow or brush thickets in the vicinity of streams. The members of this series are derived mainly from basaltic, andesitic, or other volcanic rocks, with an admixture of material derived from granites, gneiss, and sedimentary or altered sedimentary rocks. They occur as small irregular to broad extensive areas. The lighter members are of a light-gray color and porous structure, and are usually gravelly, the gravel consisting of well-rounded pebbles. The heavier members are brown to black in color, compact in structure, usually poorly drained, are sticky when wet, and have a tendency to puddle. The areas are often subject to overflow. The soils are underlain by light-gray or yellowish ashy to dark compact subsoils, with frequent occurrences of a compact adobelike structure. They are generally rich in organic matter and of a mucky consistency, except in the lighter, higher lying members.

The soils of the Gallatin series often occupy a low position of deficient drainage and are sometimes injured by the accumulation of alkali salts, but are productive when well drained. They are utilized chiefly for pasture lands and in the production of hay and grain crops. Truck crops and fruits are in favorable locations successfully grown. The Gallatin fine sandy loam, in the Lewiston area, Idaho, occupies a protected position, with climatic conditions favoring intensive fruit culture, and this type here has reached a high state of development in the production of peaches, cherries, plums, prunes, grapes, apples, and other fruits. The gravelly loam is but little developed, and is then used for hay and grain. The loam, silt loam, and clay are often subject to overflow and have not been extensively developed, but are adapted to vegetables, hay, grain, and forage crops.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Gallatin series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Gallatin gravelly loam	Montana, Washington	42,624
fine sandy loam[a]	Idaho, Montana	41,676
loam[b]	Idaho, Oregon, Washington	274,368
silt loam[c]	Idaho, Montana	41,244
clay loam	Montana	896
Total		400,808

[a] Mapped as Yakima fine sand in the Lewiston area, Idaho.

[b] Mapped as Yakima loam in Baker City, Oreg., Blackfoot, Idaho, and Walla Walla, Wash., areas.

[c] Mapped as Yakima silt loam in the Lewiston area, Idaho.

Yakima series.

The members of this series consist of ancient lake sediments, with an admixture of volcanic dust or of residual soils of fine texture, or a mixture of both. The materials have been derived mainly from basaltic and andesitic or granitic rocks. The soils occur upon mountain foot slopes, elevated lava plateaus, tablelands, ridges, or rolling hills, with intervening depressions, sloping valley plains, and elevated stream terraces. The higher areas are often rough and broken and are marked by rock outcrop and forest growth. The lower lying areas are generally gently sloping or undulating, dissected by minor stream channels, and marked by bluff and terrace lines usually strewn with waterworn gravel. The soils of this series generally occur in extensive areas. Both soils and subsoils are of a light-gray to light-brown or buff color, usually porous structure, and ashy texture from a few to many feet in depth. A thin layer of compact adobelike structure sometimes occurs in the subsoils, which are underlain by parent rock or by gravel beds occurring at considerable depths. The soils usually erode rapidly under the influence of streams or irrigation. The subsoils are frequently marked by the presence of pockets of volcanic ash, and are in general open and friable in structure.

The soils of the Yakima series take high rank in the production of grains and of intensively irrigated fruits and other special crops. The stony loam and the sand usually lie above irrigation, are of porous structure, and frequently of wind-blown drifting character, and are relatively unimportant members of the series. The sandy loam is found in Idaho, where it is extensively developed. It is level and fitted for irrigation, but is yet but little used. The fine sand occurs in elevated areas, sometimes wind blown, but when capable of irrigation and cultivation is adapted to tree fruits, vegetables, small fruits, alfalfa, and clover. The fine sandy loam is the most highly developed and intensively cultivated member of the series, and is extensively devoted to the production of choice fruits, consisting of winter apples, peaches, cherries, etc., as well as truck crops, cereals, alfalfa, clover, timothy, and hops. The loam usually occupies elevated positions, and is frequently timbered when occurring in the vicinity of Lewiston and Moscow, Idaho, but these timbered tracts are now being cleared and devoted to wheat, oats, and flax, while the production of winter apples is successfully being carried on to a limited extent. In the Baker City area, Oregon, this type is devoted mainly to the production of oats, barley, and hay crops, but under irrigation is capable of successful culture to fruits and truck crops. The silt loam in the Gallatin Valley, Montana, is devoted to dry-farmed or irrigated grains, and when under irrigation also to the production of alfalfa and clover. In the Lewiston area, Idaho, and Walla Walla area, Washington, it covers large areas of the rolling upland, being devoted principally to the production of wheat and to a limited extent to vegetables, apples, cherries, and small fruits.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Yakima series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Yakima stony loam	Washington	8,960
sand	Idaho	48,448
fine sand[a]	Idaho, Washington	38,090
sandy loam	Idaho	29,760
fine sandy loam[b]	Idaho, Washington	181,452
loam[c]	Idaho, Oregon	29,760
silt loam[d]	Idaho, Montana, Washington	291,712
Total		628,182

[a] The soil mapped as Yakima fine sand in the Lewiston area, Idaho, is the Gallatin fine sandy loam.

[b] The soil mapped as Yakima fine sandy loam in the Walla Walla area, Washington, is Columbia silt loam, and so mapped in Lewiston area, Idaho, is Yakima silt loam.

[c] The soil mapped as Yakima loam in the Baker City area, Oregon, Blackfoot area, Idaho, and Walla Walla area, Washington, is Gallatin loam.

[d] The soil mapped as Yakima silt loam in the Lewiston area, Idaho, is Gallatin silt loam.

Miscellaneous soils of the northwestern intermountain region.

The miscellaneous soils of the northwestern intermountain region consist of a number of types covering extensive areas. They occupy rolling uplands or elevated sloping plateaus and valley plains, and are usually devoted to grains under irrigation or, where climatic conditions permit, to the same crops under systems of dry-farming. Fruits and alfalfa are grown in limited quantities upon some of these soil types under favorable conditions.

The Boise loam and silt loam are underlain by more or less indurated lime hardpan on mesa lands. When this hardpan is not hard nor too near the surface the soils are adapted to grain, fruit, and alfalfa.

The Bozeman silt loam, on account of its topography, has not been developed to any great extent.

The Columbia silt loam is generally devoted to grain.

The Deer Flat fine sandy loam is very little improved for lack of available water for irrigation. When irrigated it is adapted to truck, grain, clover, and fruit.

Meadow is low-lying, flat, and poorly drained land of variable texture, frequently of some value for grass and pasturage. Much more of it can be reclaimed by simple methods of drainage, and when this is done excellent results can be secured from a variety of crops.

Rock outcrop, Rough stony land, Steep broken land, Rough broken land, and Riverwash are mainly nonagricultural land.

The Walla Walla silt loam is well adapted to wheat and barley, giving very large yields of both.

The acreage of the types so far encountered is as follows:

Area and distribution of the miscellaneous soils of the northwestern intermountain region.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Boise loam	Idaho	61,960
Boise silt loam	do	95,850
Bozeman silt loam	Montana	76,608
Columbia silt loam[a]	Washington	26,688
Deer Flat fine sandy loam	Idaho	45,380
Meadow[b]	Idaho, Oregon, Washington	29,012
Rock outcrop, Rough stony land, Steep broken land, Rough broken land, and Riverwash.	do	5,564
Walla Walla silt loam	Washington	23,360
Total		364,422

[a] Mapped as Yakima fine sandy loam in the Walla Walla area, Washington.

[b] Mapped as Muck in the Baker City area, Oregon.

ROCKY MOUNTAIN VALLEYS, PLATEAUS, AND PLAINS.

The soils of the Rocky Mountain valleys, plateaus, and plains are derived from a wide range of igneous, eruptive, metamorphic, and sedimentary rocks. The plateau and plain types occupy a more or less elevated position and have sloping, undulating, or irregular surface features. They are derived from underlying sedimentary rocks or consist of the remnants of ancient extensive mountain foot-slope material or of alluvial deposits along streams trenching and terracing the sedimentary rocks of the plateaus and plains. The mountain slope and intermountain valley types consist of residual and colluvial deposits or of ancient lacustrine or later stream sediments, occupying mountain foot slopes and narrow valleys.

The soils of the mountain slopes are usually of little agricultural value, owing to their rough surface, elevated position, and the consequent impracticability of irrigation. Those of the plateaus, valleys, and plains vary widely in economic importance, depending largely upon climatic features, topographic position, and water supply for irrigation. They range from grazing lands of nominal value to soils adapted to the most important and intensively cultivated fruit, melon, sugar beet, and other special crops.

The aggregate area of the soils surveyed in this province is 2,939,840 acres.

Billings series.

The soils of the Billings series consist of ancient stream-deposited material, with an admixture of residual and colluvial material derived from shales, sandstones, or adjacent soil bodies. They occur in old elevated stream terraces, stream flood plains, and in sloping valley plains or as second bottoms of stream valleys carved from the sedimentary rocks of elevated plains and plateaus. The surface is frequently cut by arroyos, or intermittent stream channels. The soils often cover extensive areas and are prevailingly of dark or nearly black color, and frequently of compact, sticky, adobelike structure. In depressions or along lower slopes subject to seepage from irrigation from more elevated soil bodies they are frequently poorly drained and filled with alkali. When properly drained and cultivated they are valuable and productive soils.

The soils of the Billings series are utilized mainly in the production of grains, sugar beets, and hay crops. The gravelly loam and the fine sandy loam are well-drained types free from alkali and valued for their adaptation to the production of alfalfa, sugar beets, fruits, and vegetables. In the Grand Junction area, Colorado, the peach and apple industries have reached a high state of development on the latter type. The loam, silt loam, clay loam, and clay are of less importance in fruit-producing industries, but are generally utilized for the production of sugar beets, hay crops, grains, and sometimes vegetables.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Billings series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Billings gravelly loam	Montana	11,776
fine sandy loam	Colorado, Montana	40,512
loam	Colorado	41,984
silt loam	do	9,664
clay loam[a]	Colorado, Montana	30,272
clay	Colorado, Montana, Wyoming	38,912
Total		173,120

[a] Mapped as Billings loam in the Billings area, Montana.

Colorado series.

The soils of the Colorado series consist of colluvial and alluvial material of ancient mountain foot slopes, more or less modified by or mingled with recent alluvial wash and with residual material derived from underlying sandstones, limestones, or shales. They occupy elevated undulating prairies or treeless plains, marked by occasional low, rounded ridges or hills, deep, narrow arroyos, or broad, gently sloping valleys. In eroded districts bluff or terrace lines, strewn with waterworn pebbles and outcropping ledges of sedimentary rocks, are frequent. The smaller stream valleys are often subject to overflow, and the uplands are frequently marked by depressions or local drainage basins. The transported material is derived largely from granitic and allied rocks of the Rocky Mountains. The soils and subsoils are generally of light-gray to reddish-brown or light-brown color, and frequently occur as extensive areas. They are generally productive under irrigation, but sometimes poorly drained and alkaline in depressions when subject to seepage from higher elevations.

The soils of this series usually occur in extensive bodies and frequently occupy positions above present irrigation facilities, or are sometimes rendered unproductive locally through the accumulation of seepage waters and alkali. The gravelly loam, sand, and sandy loam are well-drained types free from alkali, but frequently unirrigable owing to their position above present irrigation systems. Where irrigated, alfalfa, sugar beets, melons, vegetables, and some small fruits are profitably grown. The fine sandy loam and the loam are sometimes poorly drained, but are in general valuable soil types utilized extensively for the production of alfalfa, sugar beets, potatoes, and grains when brought under irrigation. The clay loam and the loam adobe are devoted chiefly to alfalfa and to grain crops.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Colorado series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Colorado gravelly loam	Colorado	33,408
sand [a]	Colorado, Kansas	139,520
sandy loam [b]	do	183,296
fine sandy loam	Colorado	196,480
loam	Colorado, Kansas	125,824
clay loam [c]	Colorado	832
loam adobe	do	42,880
Total		722,240

[a] Mapped as Fresno sand and Maricopa sand in the Lower Arkansas Valley area, Colorado.

[b] Mapped as Maricopa sandy loam in the Lower Arkansas Valley area, Colorado.

[c] Mapped as Maricopa clay loam in the Lower Arkansas Valley area, Colorado.

Finney series.

The Finney fine sandy loam is a very productive type, being adapted to the common grain crops, such as corn, wheat, and oats, as well as to alfalfa, from which four cuttings are obtained. Brome grass and fescue yield heavily. Corn yields from 25 to 60 bushels per acre, wheat from 20 to 25 bushels, oats from 35 to 45 bushels, and sugar beets 5 tons per acre. Much of this soil is still in pasture. Modern machinery is seen in the alfalfa fields, and the most improved farms are on this type. Generally the fine sandy loam is not strongly alkaline. The loam of this series is sufficiently rolling to admit of excellent drainage, and practically all of this soil is suitable for cultivation. It supports in some places a good growth of prairie grass. It is very productive and adapted to a diversity of crops, their growth being controlled more by the moisture supply than by the fertility of the soil. Corn, wheat, and oats are grown, while alfalfa, clover, brome grass, and fescue also do well. Corn yields from 25 to 40 bushels, wheat from 15 to 35 bushels, and alfalfa from 2 to 3 tons to the acre. Only a small area is devoted to oats. About one-half of the area surveyed is in pasture. The farmers must depend upon rainfall for water supply, since there is no water available for irrigation. The areas of Finney clay are small in extent. None of it is under cultivation, but nearly all the meadows are covered by native grasses which constitute excellent hay crops. From 1½ to 2½ tons of hay per acre are secured. Wheat and flax might be grown on the better drained meadows, where there is no danger of standing water. This type is at present of no agricultural value. The greater portion of the sandy loam of this series on the uplands is used for range purposes, though an occasional field of sorghum is found. On the second bottom lands where this soil is found alfalfa is often planted, which is more remunerative as a seed crop than as forage. The soil is free from alkali, but the subsoil contains considerable lime.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Finney series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Finney sandy loam	Kansas	6,272
fine sandy loam	Nebraska	40,128
loam	Nebraska	11,008
clay	North Dakota	3,264
Total		60,672

Fruita series.

The soils of the Fruita series are similar in origin, mode of formation, and topographic features to those of the Billings and the Mesa series. They are usually of a reddish-brown color, somewhat compact structure, though friable under cultivation, and in lower depressions are often poorly drained and filled with alkali.

The soils of this series are of a very productive character, but have been considerably injured by poor drainage and the collection of seepage waters and alkali. They are well adapted to the production of fruits and sugar beets. Apples and pears are profitably grown upon the better drained portions of areas covered by both types, but they are for the most part at present generally utilized for the production of alfalfa, grains, sugar beets, and vegetables.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Fruita series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Fruita fine sandy loam	Colorado	3,968
loam	do.	512
Total		4,480

Laramie series.

The Laramie series occurs upon mountain foot slopes and high, broken, sloping or undulating plains. The surface is often gravelly or strewn with cobbles or bowlders, and is frequently cut by intermittent stream channels or marked by rock outcrop. Depressions or basins of intermittent lakes frequently occur. The soils consist of colluvial mountain waste modified by alluvial stream wash or glacial débris, and are derived from granitic rocks, gneiss, schist, quartzites, etc., with an admixture of material from sedimentary rocks. They occur as extensive areas of dark-colored soils, generally underlain by light-colored gravelly subsoils, and are well drained and free from alkali, except for local poorly drained depressions.

The gravelly loam is a well-drained type, free from alkali, but owing to its open, porous structure and topographic position is generally at present of but little agricultural value, save for grazing purposes. The sandy loam is well adapted to general farm crops, and is devoted principally to the production of wheat, oats, potatoes, and alfalfa.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Laramie series.

Soil name.	States in which each type has been found.	Total area
		Acres.
Laramie gravelly loam	Wyoming	19,200
sandy loam	do	86,272
Total		105,472

Laurel series.

The soils of the Laurel series occupy low, nearly level or slightly sloping stream terraces and river flood plains or more elevated slopes adjacent to intermittent streams subject to flood. They consist of recent alluvial sediments deposited from the turbid flood waters of wide, shallow, shifting streams traversing elevated valleys, plains, or plateaus. The soils vary in color from light gray to reddish brown or black, according to position and the quantity of organic matter present, and are often poorly drained and filled with alkali.

The fine sand and the fine sandy loam are of loose, leachy character and subject to overflow. They are usually devoted to pasture or to sugar beets, truck crops, and, when the water table does not too closely approach the surface, to alfalfa. The fine sandy loam occurring in the Russell area, Kansas, and Sarpy County, Nebr., is utilized chiefly in the growing of corn and alfalfa. The loam and loam adobe are devoted mainly to the production of alfalfa, sugar beets, and grains. The clay loam, which occurs in the San Luis Valley, Colorado, is not, however, esteemed desirable for grain or alfalfa, but is utilized mainly for pasture.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Laurel series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Laurel gravelly loam	Nebraska	16,448
fine sand[a]	Colorado, Kansas, Nebraska	16,512
sandy loam	Colorado, Kansas, Montana, Nebraska, Wyoming	136,960
fine sandy loam	Kansas, Nebraska, North Dakota	21,632
loam	Colorado, Kansas, Nebraska, North Dakota	118,016
silt loam	North Dakota	18,880
clay loam	Colorado, Kansas, North Dakota	27,008
loam adobe	Kansas	1,472
clay	North Dakota	6,656
Total		363,584

[a] Mapped as Fresno fine sand in the Lower Arkansas Valley, Colorado.

Mesa series.

In origin, mode of formation, and topographic features the soils of the Mesa series are similar to those of the Billings and the Fruita series. They consist of former flood-plain deposits now existing as old elevated river terraces or mesa lands. The surface is often rough and hilly. The soils generally vary from light gray to chocolate brown in color, are friable to compact in structure, and are underlain by shale and sandstone rock. They are sometimes poorly drained and impregnated with alkali in small local depressions.

The fine sandy loam occurs mainly in uncultivated tracts, which are gradually coming into use for the production of orchard fruits, alfalfa, and truck crops, for which this soil is admirably adapted. The clay loam and clay are sometimes poorly drained, and these types are chiefly utilized in the cultivation of sugar beets, alfalfa, and grain.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Mesa series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Mesa fine sandy loam	Colorado	34,432
clay loam	do	2,240
clay	do	22,464
Total		59,136

Morton series.

The Morton series includes soils derived principally from the sandstones and shales of the Laramie formation. They are brown in color, owing to the accumulation of a considerable amount of organic matter. Being formed in a region of low rainfall, these soils and especially the subsoils are usually rich in lime.

The most important soil in the Morton series is the loam which comprises the greater part of the safe farming land in the upland portion of Morton County, N. Dak. It is very productive, retentive of moisture, and easily tilled. In average seasons it produces good crops of wheat, flax, and oats. The fine sandy loam, while not so retentive of moisture as the loam, is usually a good farming soil and for many years it has produced a good average of profitable crops. The texture adapts it to truck crops and vegetables that require a rapid growth during a short season. For this reason it is better adapted to corn than are some of the other soils, but the possibility of injury from drought is greater than in the heavier soils. The stony loam furnishes excellent grazing. The open, porous nature and topography of the fine sand render it unable to retain moisture, so that the areas have a very low agricultural value except for grazing. In McKenzie County, N. Dak., where the silt loam has been mapped none of the type has ever been broken up for cultivation and probably not more than 2 per cent is mowed for hay. It is used almost entirely for grazing. It is one of the best upland soils of this section and if climatic conditions were favorable it would produce fine crops. The clay loam, clay, and gumbo are used for pasture.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Morton series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Morton stony loam	North Dakota	48,128
fine sand	do	4,352
fine sandy loam	do	117,952
loam	do	163,456
silt loam	do	104,576
clay loam	do	17,024
clay	do	704
gumbo	do	8,448
Total		464,640

San Luis series.

The material forming the San Luis series was derived originally from volcanic rocks, principally trachyte, and represents ancient lacustrine sediments or lake beds, more or less modified by subsequent alluvial wash, wind drifting, and weathering. The soils occupy filled valleys as broad, nearly level, or gently sloping plains, the surface being broken only by small mounds or ridges or by forms produced by wind-drifting. They occur as small irregular to broad, extensive areas, often gravelly, the gravel consisting of medium to fine fragments. The soils are of reddish-brown color, porous structure, and are underlain by sands and coarse, rounded gravel. The lower lying bodies are often subject to injury from seepage and accumulation of alkali from irrigation upon higher adjacent soils.

The sand is a loose, porous soil requiring heavy irrigation, which has been followed in the San Luis Valley, Colorado, where these soil types occur, by more or less injury from the collection of seepage waters and alkali. The same is true more or less of the sandy loam. Both these soils are devoted mainly to the production of grains and field peas. The loam is a poorly drained type containing more or less alkali and is of minor agricultural importance.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the San Luis series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
San Louis sand	Colorado	136,960
sandy loam	do	196,992
loam	do	9,088
Total		343,040

Wade series.

The Wade series consists of brown to dark-brown alluvial soils formed by the reworking of the sandstones and shales belonging principally to the Laramie formation. They occur throughout the area where the Morton soils form the uplands. They contain a considerable amount of lime, and some of the more poorly drained areas contain alkali.

The soils of the Wade series are good farming soils when rainfall is sufficient. The fine sandy loam is now largely under cultivation in Morton County, N. Dak., and oats, flax, millet, and corn, and, to a less extent, wheat, are grown with profitable results. Heretofore oats have been the most successful and profitable crop. All kinds of vegetables may be produced in large quantities when there shall arise a demand for such products, but at present they are grown only for home use. The silt loam has a large amount of humus that gives it a dark color and a loamy character, which makes it easily tilled. A considerable proportion is cultivated, as it is a favorite type of soil with the homesteader. It is very productive, withstands drought well, and is well adapted to any of the usual field crops. The loam is the most desirable of the series, agriculturally. The soil is retentive of moisture and advantageously situated for purposes of general farming, and especially for stock raising. None of the clay has yet been cultivated, although it is a productive soil, and aside from the difficulties of tillage it should be very desirable farming land. The small areas make excellent hay meadows.

The acreage of the types so far encounted is as follows:

Area and distribution of the soils of the Wade series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Wade fine sandy loam	North Dakota	12,608
loam	do	8,576
silt loam	do	28,352
clay	do	8,256
Total		57,792

Miscellaneous soils of the Rocky Mountain valleys and plains.

The Fort Collins loam is generally level, with occasional slight undulations. It is for the most part a residual soil formed by the weathering in place of shaly sandstones and sandy shales. The type is well adapted to wheat, oats, barley, alfalfa, sugar beets, potatoes, and apples.

Very little of the Gannett fine sand is cultivated, most of it being utilized as pasture. It occurs in the bottoms along the foot of the sandhills in Nebraska.

The Lancaster fine sandy loam is very limited in extent and is not a good soil for general farming.

The North Platte loam occupies level second bottoms along the Platte River. Corn and alfalfa produce well, and wheat, sugar beets, fruits, and vegetables should be fairly successful.

The Orman clay consists of material washed from the Pierre shale and deposited in lakes. At the present time hardly any of this land is under cultivation, but it is probably well adapted to crops grown in this section. The soil contains considerable alkali, and proper methods to guard against injury from this source should be adopted when it is put under irrigation.

The Osgood fine sandy loam represents colluvial wash from the more sandy loess in central Nebraska. It is a fine soil, producing good crops of corn, wheat, oats, alfalfa, sugar beets, and hay.

The Pierre clay is quite extensively developed, being derived from the Pierre shale. The acreage farmed is very small, and the type is used largely for grazing purposes. It gives a fair growth of native grasses, and the lower lying portions are sometimes cut for hay. Small irrigated areas give good crops.

The Pierre clay loam supports a good growth of grass and is used to a limited extent as a range for stock. Near the streams the growth of grass is heaviest, and here it is cut for hay. Some of the type is farmed without irrigation, the principal crops being alfalfa and oats, with some wheat and corn. The yields vary widely, being dependent upon the rainfall.

Rock outcrop, Rough stony land, Steep broken land, Rough broken land, and Riverwash are mainly nonagricultural land.

The Scoria gravel and Epping clay are of little agricultural importance.

Sandhill and Dunesand are deep sands of little agricultural value.

Swamp and Marsh comprise areas covered with water the greater part of the year and unfit for agriculture, except where drained and protected from tidal or fluvial overflow. When reclaimed much of this land will become very productive.

Both dry farming and farming under irrigation are practicable on the Vale fine sandy loam. In the dry-farming section it produces good crops of alfalfa, oats, and corn in seasons of average rainfall. Under irrigation alfalfa produces 5 to 7 tons, oats 60 to 70 bushels, and wheat 25 to 35 bushels per acre. Corn also gives good returns when not damaged by early frosts.

On account of its steep surface slope a large part of the Vale gravelly sandy loam is suited only to pasture. Under irrigation the more level areas should prove well adapted to such fruits as thrive on gravelly soils in this climate.

Alfalfa and small grains, principally oats and wheat, do well on the Vale loam, and the yields approximate those obtained on the fine sandy loam. In the Red Water and Spearfish valleys, South Dakota, this soil has proved well adapted to apples, plums, cherries, and small fruits.

The acreage of the types so far encountered is as follows:

Area and distribution of the miscellaneous soils of the Rocky Mountain valleys and plains.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Epping clay	North Dakota	384
Fort Collins loam	Colorado	14,144
Gannett fine sand	Nebraska	8,448
Lancaster fine sandy loam	do	2,368
Meadow	do	46,272
North Platte loam	do	23,936
Orman clay	South Dakota	14,912
Osgood fine sandy loam	Nebraska	16.320
Pierre clay	South Dakota	41,088
Pierre clay loam	do	24,192
Rock outcrop, etc	Colorado, Kansas, Nebraska, North Dakota, Wyoming.	86,080
Sandhill and Dunesand	Colorado, Kansas, Nebraska	248,192
Scoria gravel	North Dakota	25,920
Swamp and Marsh	Colorado, Montana	3,648
Vale fine sandy loam	South Dakota	23,936
Vale gravelly sandy loam	do	2,304
Vale loam	do	3,520
Total		585,664

ARID SOUTHWEST.

The soils of the arid Southwest are mainly of colluvial, alluvial, and lacustrine origin. They occupy mountain foot slopes, alluvial fans, débris aprons, or sloping plains of filled valleys, sloping or nearly level plains, and bottoms of stream valleys or sinks and drainage basins. The principal colluvial soils of this region are also common to the Pacific coast. The climate of the arid Southwest is characterized by semitropical desert conditions, and where the soils are not capable of irrigation they have little or no present agricultural value. The aggregate area of the soils surveyed in this province is 1,131,155 acres.

Gila series.

The Gila series consists of recent stream deposits derived from a variety of rocks, and occurs over river flood plains and lower stream-formed terraces. The soils of this series are generally subject to overflow, and are often eroded or modified by torrential floods, cut by stream channels, more or less wind drifted, and frequently covered with dense thickets of willow, cottonwood, mesquite, canaigre, or other small timber or bushes. They are of light to dark brown color. The soils of this series are sometimes interstratified with minor layers of heavier sediments and are distinguished from those of the Imperial series by being underlain at varying depths by coarse river sands and gravels. The fine sandy loam and the fine sand, when irrigable and well drained, are well adapted to the production of fruit, truck crops, melons, potatoes, and alfalfa, but the surface is sometimes uneven and the soils are occasionally poorly drained or affected with alkali, The other soils of this series are frequently subject to overflow or are poorly drained and contain alkali, but when well drained they are adapted to alfalfa, grains, or other general farm crops.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Gila series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Gila fine sand[a]	Arizona, California, New Mexico	81,042
fine sandy loam[b]	Arizona	43,794
loam[c]	Arizona, California	79,232
silt loam	.....do	12,672
clay loam	.....do	24,384
clay	.....do	17,751
Total		208,875

[a] Mapped as Imperial sand in the Yuma area, Arizona-California.

[b] Mapped as Gila fine sandy loam in the Solomonsville area, Arizona, and the Imperial area, California.

[c] Mapped as Imperial sandy loam in the Yuma area, Arizona-California.

Imperial series.

The Imperial series consists of old marine or lacustrine sediments more or less covered or modified by subsequent river overflow deposits. The soil types of this series are derived from a variety of rocks and usually occur as extensive bodies covering low, level, or slightly sloping valley floors. Unlike the soils of the Gila series, they are underlain to great depths by heavy sediments of close and more or less impervious nature. The surface is sometimes marked by bluff or shore lines, sloughs, or stream channels, and is usually considerably modified by drifting. The soils are generally of light or reddish color, and in the heavier members are frequently poorly drained and filled with alkali. The sand and sandy loam are important types of this series adapted to the production of fruits, truck crops, and alfalfa or forage crops under irrigation. The clay loam and the clay frequently contain an excess of alkali salts and are cultivated with difficulty, owing to heavy or fine texture and compact structure, but if well drained are suitable for the production of alfalfa, sorghum, and millet.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Imperial series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Imperial sand[a]	California	1,792
sandy loam[b]	.....do	126,656
clay loam	.....do	341,056
clay	.....do	46,912
Total		516,416

[a] The soil mapped as Imperial sand in the Yuma area, Arizona, is the Gila fine sand.

[b] The soil mapped as Imperial sandy loam in the Yuma area, Arizona-California, is the Gila fine sandy loam.

Indio series.

The Indio series occurs in desert valleys, covering sloping valley plains, upper valley slopes at the foot of mountain ranges, and mountain foot slopes. The soils are derived mainly from granitic rocks, mingled with some shale and sandstone material, and are formed by colluvial and alluvial wash from intermittent or torrential streams, and in certain cases have been deposited in the waters and modified by the shore deposits of ancient lakes or bays. They are generally of light color and porous structure, usually underlain by coarser sands and gravels, and their surface is rough and hilly, scarred by the channels of intermittent streams or drifted by winds. The fine sand is an important agricultural type of this series, adapted particularly to the production of sweet potatoes, melons, and vegetables. It is of special importance in the cantaloupe industry of the arid Southwest. It is also a good soil for forage crops. The fine sandy loam is adapted to the same crops, though often poorly drained and affected with alkali. In most cases the gravelly loam and the sand either lie above the irrigation systems or have a surface too uneven for irrigation; but when irrigable and free from alkali they are usually adapted to the production of fruits and vegetables.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Indio series.

Soil name.	State in which each type has been found.	Total area.
		Acres.
Indio gravelly loam	California	43,328
sand [a]	do	50,112
fine sand [b]	do	36,082
fine sandy loam [c]	do	42,432
Total		171,904

[a] Mapped as Fresno sand in the Indio area, California.
[b] Mapped as Fresno fine sandy loam in the Indio area, California.
[c] Mapped as Fresno sandy loam in the Indio area, California.

Miscellaneous soils of the arid Southwest.

The Pecos sandy loam is a well-drained soil, free from alkali and is usually recognized as the best general farming land of the localities in which it occurs.

The Roswell fine sandy loam and the Roswell loam are rather poorly drained and frequently contain injurious amounts of alkali, but when well drained and free from alkali are well adapted to the production of alfalfa and general farm crops.

The Yuma sand has a level, smooth surface, is well drained, and is adapted to the production of citrus fruits, figs, grapes, vegetables, melons, etc.

The Glendale clay loam is usually well drained, free from alkali, and adapted to grain, alfalfa, and in the case of the lighter phases to fruits.

The Pecos conglomerate is a nonagricultural type.

Gypsum is found on level bench lands in New Mexico. It is derived from gypsum deposits and is of little agricultural value.

Meadow consists of low-lying, flat, and poorly drained land of variable texture. It is frequently of some value for grass and pasturage. Much more of it can be reclaimed by simple methods of drainage, and when this is done excellent results can be secured from a variety of crops.

Rock outcrop, Rough stony land, Steep broken land, Rough broken land, and Riverwash are mainly nonagricultural land.

The acreage of the types so far encountered is as follows:

Area and distribution of the miscellaneous soils of the arid southwest province.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Glendale clay loam	Arizona	52,040
Gypsum	New Mexico, Wyoming	11,630
Meadow	New Mexico	7,940
Pecos conglomerate	.....do	11,680
Pecos sandy loam	.....do	36,310
Roswell fine sandy loam	.....do	9,090
Roswell loam	.....do	2,730
Yuma sand	Arizona	94,400
Rock outcrop, etc	.....do	8,140
Total		233,960

PACIFIC COAST.

The soils of the Pacific coast, including those of the coastal and interior mountain ranges, foothills, and valleys, have been classified into a number of series, varying in field characteristics, topography, origin and mode of formation, and agricultural importance. They range from residual and colluvial soils of the mountain sides, foot slopes, and foothills, to deep and extensive river flood plains and delta sediments, and ancient and modern shore and marine lacustrine deposits. While some of these series are confined to a single coastal or interior mountain range or valley, others are of wider range and extend over several different physiographic regions. The value of these soils and their adaptation to crops is dependent largely upon the possibilities of irrigation and upon local conditions of rainfall and temperature, all of which are to a great extent dependent upon topography. They range in agricultural importance from those devoted only to extensive grain farming to the most valuable and intensively cultivated lands devoted to citrus and deciduous fruits, vines, small fruits, and other special crops. The aggregate area of the soils surveyed in this province is 4,593,881 acres.

Anderson series.

The soils of the Anderson series consist of reddish-gray or light-red alluvial soils occupying upper valley plains and the bottoms of intermittent streams. They are usually gravelly, sometimes underlain at less than 6 feet by stream gravels or by compact clays and clay loams, and often support a considerable growth of brush and timber. When not too gravelly they are adapted to the production of peaches, pears, prunes, and small fruits, but are, so far as mapped at present, inextensive types and of secondary agricultural importance, the Anderson gravelly loam being the prevailing and most important soil of the series.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Anderson series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Anderson gravelly loam	California	14,528
fine sandy loam	do	3,520
Total		18,048

Fresno series.

The soils of the Fresno series are characterized by prevailing light-gray colors, but are sometimes light brown or reddish brown. They are generally underlain by subsoils of fine ashy texture, light color, and compact, close structure, usually separated from the overlying soil by an alkali carbonate hardpan of white or light-gray color. The hardpan softens slowly upon the application of irrigation water, but is normally impenetrable to the roots of growing plants. The series is composed of old delta deposits formed by shifting streams and mountain torrents and occurring as broad, low alluvial delta cones. The soils occupy gently sloping plains or slightly rolling valley slopes, generally treeless, and are not usually overflowed. The soil material of this series is mainly of granitic origin, although in part derived from volcanic and sedimentary rocks. The lighter members, since they occupy higher positions, are generally well drained. The lower lying areas frequently require drainage, being subject to seepage from higher lying tracts and also contain some alkali. The sand and fine sand, with intensive methods of cultivation and irrigation, are used for the production of peaches, apricots, cherries, prunes, figs, walnuts, and raisin and wine grapes. They are also well adapted to alfalfa and to vegetables under irrigation. The sandy loam and fine sandy loam are productive soils and excellently adapted to fruits and alfalfa, though large areas have been damaged by seepage and the accumulation of alkali.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Fresno series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Fresno sand [a]	California	193,526
fine sand [b]	do	8,128
sandy loam [c]	do	5,952
fine sandy loam [d]	do	90,975
loam [e]	do	5,824
Total		304,405

[a] The soil mapped as the Fresno sand in the Lower Arkansas Valley area, Colorado, is the Colorado sand; that mapped as Fresno sand in the Indio area, California, is Indio sand; that mapped as the Fresno sand (gravelly phase) in the Ventura area, California, is Maricopa sand; that mapped as Fresno sand in Bakersfield, Los Angeles, Lower Salinas Valley, Sacramento, San Bernardino, San Gabriel, and Santa Ana areas, California, is Hanford sand; and that mapped as the Fresno sand in Provo area and in Weber County, Utah, is Jordan sand.

[b] The soil mapped as the Fresno fine sand in Lower Arkansas Valley, Colorado, is Laurel fine sand; that mapped as Fresno fine sand in Bakersfield and Los Angeles areas, California, is Hanford fine sand; and that mapped as Fresno fine sand in Sacramento area, California, is Hanford fine sandy loam.

[c] The soil mapped as Fresno sandy loam in Fresno and Hanford areas, California, is the Fresno fine sandy loam, and that mapped as Fresno sandy loam in the Indio area, California, is the Indio fine sand.

[d] The soil mapped as Fresno fine sandy loam in the Lower Arkansas Valley area, Colorado, is the Marshall silt loam; that mapped as Fresno fine sandy loam in Weber County and in Bear River area, Utah, is Weber fine sandy loam; that mapped as Fresno fine sandy loam in Indio area, California, is Indio fine sandy loam; that mapped as Fresno fine sandy loam in the Ventura area, California, is the Oxnard loam; that mapped as Fresno fine sandy loam in the Bakersfield, Lower Salinas Valley, Los Angeles, San Bernardino, San Gabriel, and Santa Ana areas, California, is the Hanford fine sandy loam; and that mapped as Fresno fine sandy loam in San Jose area, California, is the Hanford silt loam.

[e] Mapped as Maricopa loam in Bakersfield area, California.

Hanford series.

The soils of the Hanford series consist of recent alluvial materials derived from a great variety of rocks and deposited as river and delta plains. The lighter members sometimes consist largely of mining débris and overlie Pleistocene sediments and hardpan. They are generally light gray to buff in color, but become dark drab, brown, or nearly black in the case of some of the heavier members occupying low-lying positions. All the members of the series are subject to much variation in depth, color, and character of underlying material. The surface is generally level, slightly sloping, or sometimes uneven, and is frequently marked by sloughs or the interlacing channels of streams, many of which carry water only in times of flood and disappear in sandy washes. The heavier members are frequently marked by an adobe structure, and the soils are generally free from gravel or bowlders. The lighter members and higher lying soil bodies are usually well drained and are not affected by seepage caused by irrigation, while the natural drainage is sometimes deficient in the case of lower lying areas occupying present stream flood or overflow delta plains, where protection by levees becomes necessary. While similar to the soils of the Fresno series in mode of formation, they generally occupy a lower topographic position, are of more recent origin, are frequently subject to overflow, and, unlike the former, often support a growth of swamp vegetation, brush and willow thickets, and timber in the river bottoms and lower valley plains. The heavier members are also usually of darker color, while the underlying white hardpan and subsoils of ashy texture common in the Fresno series are wanting here. The soils are usually productive and are especially adapted to fruits, vines, vegetables, and truck crops when well drained, free from alkali, and irrigated. The lighter soils of the Hanford series, consisting of the sand, fine sand, sandy loam, and fine sandy loam, are productive and easily cultivated, and utilized in the production of alfalfa, pears, stone fruits, grapes, English walnuts, small fruits, asparagus, celery, and other truck crops. The sand is, however, while a fair fruit and truck soil when well irrigated, of a somewhat leachy character and deficient in organic matter. The soils of this series are also often subject to overflow, and, with the exception of the sand in some places, poorly drained and affected with alkali. The silt loam is also devoted to the production of potatoes, beans, sugar beets, and hops, in addition to the crops enumerated above.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Hanford series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Hanford gravel	California	4,544
sand[a]	do	224,680
fine sand[b]	do	118,338
sandy loam	do	19,860
fine sandy loam[c]	do	151,194
silt loam[d]	do	73,137
clay loam[e]	do	17,896
clay adobe[f]	do	12,672
Total		622,321

[a] Mapped as the Fresno sand in the Bakersfield, Los Angeles, Lower Salinas, Sacramento, San Bernardino, San Gabriel, and Santa Ana areas, California.

[b] Mapped as Fresno fine sand in the Bakersfield and Los Angeles areas, California.

[c] Mapped as the Fresno fine sand in the Sacramento area, California, and as the Fresno fine sandy loam in Bakersfield, Lower Salinas, Los Angeles, San Bernardino, San Gabriel, and Santa Ana areas, California.

[d] Mapped as the Fresno fine sandy loam in San Jose area, California, and as the Sacramento silt loam in the Sacramento area, California.

[e] Mapped as the Oxnard silt loam in the Bakersfield area, California.

[f] Mapped as the Salinas gray adobe in the Sacramento area, California.

Maricopa series.

The Maricopa series consists of unassorted colluvial and only partially assorted alluvial material formed by soil creep and direct washing from the mountain sides and by the deposits of intermittent, shifting, torrential streams. The soils of this series are derived from a variety of rocks, but generally from those of granitic and volcanic character. They occupy mountain foot-slopes, delta cones or fans, débris aprons, and sloping plains of filled valleys, and also occur in stream valleys as the product of a series of minor secondary fans or cones emerging from adjacent more elevated slopes or mesa lands. They are generally treeless, and support only a desert vegetation, except when irrigated, are frequently cut by arroyos, and the lighter members are usually gravelly and often strewn with bowlders. These soil bodies vary from small areas of irregular outline to broad, extensive, uniform sheets. The soils are generally of dark color and loose, porous structure. They are generally well drained and free from alkali, and where capable of irrigation are well adapted to fruits, vines, and general farm crops. The gravelly loam and the gravelly sand are well drained and free from alkali, but in many cases can not be irrigated, and are then devoted to grazing or dry-farming to grains or to the production of grapes. Extensive areas are, however, irrigated and used for the production of grains, grapes, citrus fruits, and stone fruits. In the San Gabriel area these types are used extensively for grains and for the production of citrus fruits. In the San Jose area large quantities of early peaches, apricots, prunes, other stone fruits, and grapes are produced. The sand is sometimes broken, hilly or wind-blown in character, but when favorably situated for irrigation is adapted to fruits, vines, and general farm crops. In the Ventura area it has been found a valuable soil for lima beans. The sandy loam and the fine sandy loam are usually free from alkali and well drained. Under irrigation they are good soils for alfalfa, grains, citrus fruits, deciduous fruits, small fruits, and truck crops. In the Los Angeles area they are devoted quite extensively to grapes, alfalfa, strawberries, lemons, and winter vegetables. The silt loam and the clay loam are not well drained, and accumulations of alkali occur. The best-drained areas produce alfalfa, wheat, barley, sorghum, and in some localities sugar beets.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Maricopa series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Maricopa gravelly sand	California	194,886
gravelly loam[a]	Arizona, California	98,226
sand[b]	do	28,318
sandy loam[c]	do	47,680
fine sandy loam	do	112,858
loam[d]	Arizona	33,514
silt loam	do	11,648
clay loam[e]	do	8,713
Total		535,843

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[a] The soil mapped as Maricopa gravelly loam in the Provo area, Utah, is the Bingham gravelly loam; that mapped as Maricopa gravelly loam in the Baker City area, Oregon, is the Bridger gravelly loam; and that mapped as Maricopa gravelly loam in Los Angeles area, California, is the Maricopa fine sandy loam. Mapped as Maricopa sandy loam in San Bernardino area, California, and that mapped as Maricopa gravelly loam in the Solomonsville area, Arizona, is Maricopa loam.

[b] The soil mapped as Maricopa sand in the Lower Arkansas Valley area, Colorado, is the Colorado sand. Mapped as Fresno sand (gravelly phase) in Ventura area, California.

[c] The soil mapped as Maricopa sandy loam in Baker City area, Oregon, is the Bridger loam; soil mapped as Maricopa sandy loam in Lower Arkansas Valley, Colorado, is Colorado sandy loam; and that mapped as Maricopa sandy loam in Salt River Valley, Arizona, is Maricopa fine sandy loam.

[d] The soil mapped as Maricopa loam in Bakersfield area, California, is Fresno loam.

[e] The soil mapped as Maricopa clay loam in Lower Arkansas Valley area, Colorado, is Colorado clay loam.

Oxnard series.

The soils of the Oxnard series consist of delta-plain deposits, colluvial and alluvial wash from foothills and higher adjacent soil bodies, and occasional small areas of residual material. They are derived mainly from sandstones, shaly sandstones, and shales, and occur upon rolling hills, sloping, elevated, and dissected mesa lands and plains, and lower nearly level valley and delta plains. They usually occupy a less elevated position than the soils of the Maricopa series, are derived from less elevated foothills and ranges, and are lacking in the granitic material of the former series. They are generally of dark color and are most frequently underlain by heavier subsoils, which, however, do not have the red color and adobe structure of the subsoils of the Placentia series, occupying a similar topographic position. The soils of the Oxnard series occur in the vicinity of Oxnard, Cal., and are recognized as particularly adapted to the production of lima beans, which industry has been here highly developed. The gravelly loam, sand, sandy loam, loam, and silt loam are utilized extensively for this purpose. In other parts of southern California these types are also devoted to the production of walnuts, berries, truck crops, and citrus and deciduous fruits. The soils of this series are usually productive, but sometimes local areas are poorly drained or marked by the accumulation of alkali salts. The heavier and slightly alkaline areas are usually best adapted to the production of barley or of sugar beets, which are extensively produced upon the heavier types of this series.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Oxnard series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Oxnard gravelly loam	California	16,270
sand	do	56,520
sandy loam	do	75,600
fine sandy loam	do	22,848
loam [a]	do	19,812
silt loam [b]	do	31,240
clay loam	do	30,574
clay loam adobe	do	134,598
Total		387,462

[a] The soils mapped as Oxnard loam in Los Angeles, San Jose, and Ventura areas, California, are Oxnard clay loam. Mapped as Fresno fine sandy loam in Ventura area, California.

[b] The soil mapped as Oxnard silt loam in Bakersfield area, California, is Hanford clay loam.

Placentia series.

The soils of the Placentia series vary considerably in origin, mode of formation, and topographic position. In general, however, they consist of colluvial waste and of alluvial and colluvial deposits of intermittent or torrential mountain streams, though in some cases they are composed essentially of residual material. In nearly all cases they have been subject to considerable modification subsequent to their formation by weathering and through the addition of alluvial wash from minor streams. They occur upon undulating hills, mountain foot slopes, mesa lands, and broad, uniformly sloping fan deltas and higher valley plains. They are distinguished from the soils of the Maricopa series of somewhat similar topographic position and mode of formation, by the prevailing reddish-gray to reddish-brown color and in being underlain by indurated sands, shaly sandstones, disintegrated granite, or more generally by heavy, compact red loams or clay loams of tough, impervious adobe structure. The soils of this series are derived mainly from granitic rocks, shaly sandstones, and sandstones carrying a large amount of granitic material. They are generally well drained, free from alkali, and frequently of somewhat refractory nature. They are tilled with difficulty, but possess marked moisture-retaining properties and include large areas of valuable lands devoted to grains, general farm crops, citrus and deciduous fruits, beans, and other special crops. The sandy loam, fine sandy loam, and loam are productive soils, and when irrigated are extensively devoted to citrus fruits, walnuts, olives, prunes, peaches, apricots, grapes, cherries, berries, and vegetables. They frequently occur, however, in extensive elevated areas above the reach of irrigation waters, and under such circumstances are usually devoted to the production of grains by dry farming. The sandy adobe, loam adobe, and clay loam adobe usually occupy sloping plains or an elevated position, are retentive of moisture, well adapted to dry farming of grains, and, when irrigated, to alfalfa, walnuts, and citrus and deciduous fruits.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Placentia series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Placentia sandy loam[a]	California	66,688
fine sandy loam	do	354,333
loam[b]	do	32,904
clay loam	do	2,816
sandy adobe	do	36,454
loam adobe	do	16,820
clay loam adobe	do	8,916
Total		518,431

[a] The soil mapped as Placentia sandy loam in the Ventura area, California, is the Placentia loam, and that mapped as Placentia sandy loam in Lower Salinas Valley, Los Angeles, San Bernardino, San Gabriel, San Jose, and Santa Ana areas, California, is Placentia fine sandy loam.

[b] The soil mapped as Placentia loam in the San Bernardino area, California, is the Placentia clay loam.

Redding series.

The soils of the Redding series are derived from the Red Bluff formation, consisting of ancient alluvial valley deposits. They are of a red to deep-red color, usually gravelly, and sometimes carry large amounts of rounded cobbles, and are underlain by heavy red subsoils and partially indurated clay-iron hardpans, frequently with gravel. They occupy lower rolling foothills and sloping upland dissected plains. The gravelly loam is the prevailing and most important soil in the northern part of the Sacramento Valley, so far as mapped. Where there is not an excess of cobbles or where it is not underlain at shallow depths by hardpan it is well adapted to the production of choice peaches and small fruits. It is not suited to prunes or other deep-rooted trees. Strawberries and bramble fruits yield abundantly, and if irrigated the shallower soils not adapted to tree fruits could be utilized for these small fruits. The hardpan is nearer the surface in the loam than in the gravelly loam. Owing to this fact and its location in unirrigated portions of the valley, it is of secondary agricultural importance, being used principally for grazing or for dry-farmed wheat.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Redding series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Redding loam	California	14,272
gravelly loam	do	57,216
Total		71,488

Sacramento series.

The Sacramento series consists of recent stream deposits ranging in color from light gray in the case of the soils of coarser texture to darker colors in the case of the silty clay loams. The soils are derived from a great variety of rocks, and have been transported long distances, and deposited from shifting river currents or from relatively stagnant flood waters covering flood plains. They are usually 6 feet or more in depth and often subject to overflow when not protected by levees, but when so protected are usually productive and generally adapted to the intensive production of sugar beets, truck crops, or fruits. The Sacramento series is very important, covering a large area and varying widely in texture. The fine sandy loam is the most important prune soil in the Anderson Valley, having played a large part in the development of this industry in that section. It is also a good fruit soil generally, being adapted to peaches, pears, and grapes. Many of the orchards found upon it are in a high state of cultivation. It is also suited to alfalfa and vegetables, and when irrigated sugar beets may be grown upon it. To some extent it is dry-farmed to grain and to hops under intensive cultivation. The silt loam type of this series is devoted chiefly to grazing, but when irrigated it is adapted to alfalfa, sugar beets, and truck, as well as to sorghum and other forage crops. It is also dry-farmed to grain. In some places berries do exceedingly well and it also produces potatoes and hops of excellent quality. Citrus fruits are occasionally found on the silt loam. The gravelly sandy loam type is generally of little agricultural value. The heavier phases are better suited to crops, and when well irrigated will give fair yields of alfalfa and support good orchards. It is sometimes dry-farmed to grain. A very productive type of this series is the silty clay loam, upon which is grown to a considerable extent alfalfa and other forage crops, hops, fruits, and truck crops. In some places it yields excellent citrus fruits, but only to a limited extent. Under irrigation better results are obtained. The silty clay is used chiefly for grazing, but with a moderate amount of water alfalfa and sugar beets may be grown upon it. It is believed that with deep and thorough plowing and frequent cultivation fair yields of corn, sorghum, and other forage crops may be grown without water. When artificially drained and protected from overflow the clay loam type of the Sacramento series is very productive, producing timothy and other grasses, potatoes, onions, beans, etc. The greater part of the loam of this series is devoted to grazing, but when irrigated it is adapted to alfalfa, sugar beets, truck crops, and fruits. It is sometimes dry-farmed.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Sacramento series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Sacramento gravelly sandy loam	California	20,224
fine sandy loam	do	4,224
loam	do	14,144
silt loam[a]	do	17,408
clay loam	do	41,088
silty clay loam	do	50,368
silty clay	do	26,368
Total		173,824

[a] The soil mapped as Sacramento silt loam in the Sacramento area, California, is Hanford silt loam.

Salem series.

The Salem series occurs upon rolling hills as residual soils, upon sloping plains as alluvial and colluvial soils, and upon level valley plains and stream bottoms as recent alluvial deposits. The soils of this series are derived from sandstones, crystalline and schistose rocks, and a dense, highly ferruginous basalt. They are from red to dark brown or black in color, and are generally devoted to grains, fruits, truck crops, and hops. The fine sandy loam and the silt loam are utilized in the production of truck crops, small fruits, and hops, the silt loam being also devoted to grains. They are productive soils and usually well drained, except when subject to overflow. The clay occupies a more elevated position occurring upon rolling and dissected hills. It is usually well drained and devoted to the culture of grains, hops, apples, prunes, and peaches.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Salem series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Salem gravelly loam	Oregon	13,120
fine sandy loam	do	3,648
silt loam	do	78,656
clay	do	86,400
Total		181,824

San Joaquin series.

The soils of the San Joaquin series are of prevailingly red color, frequently gravelly, both gravel and soil particles consisting largely of well-worn quartzose material. They are commonly underlain at a depth of 2 or 3 feet by red or reddish-brown indurated clay or sandy layers cemented by iron salts into a firm, impervious, impenetrable hardpan, which may, however, more deeply underlie the soil or may outcrop at the surface. The reddish color of the soils and subsoils and the occurrence of the underlying red hardpan are readily distinguished characteristics marking this series. The soils are generally of compact structure, sticky, and quite readily puddled when wet and frequently separated from the underlying hardpan by subsoils of true adobe structure. They consist of old sediments deposited in the waters and about the shores of lakes or bays of early Pleistocene age, modified by more recent reworking or by alluvial wash from adjacent formations. They occupy valley plains extending from lower rolling foothills down to level valley floors and margins of present stream flood plains. The areas are usually treeless, except in the immediate vicinity of stream channels. The soils generally occur as extensive areas. The natural drainage is usually restricted by topographic position, deficient slope, and the presence of underlying impermeable hardpan, except in case of the lighter, deeper members and areas occupying higher well-developed slopes. The soils of this series are generally devoted to dry-farming to grains, but the lighter, deeper, and better-drained members are sometimes devoted to citrus and stone fruits, grapes, small fruits, and truck crops, and give excellent yields under proper irrigation, drainage, and cultivation. The heavier members are frequently marked by an adobelike structure. Soils, subsoils, and hardpan are usually free from alkali. The surface is frequently marked by the presence of small "hog wallow" mounds. The soils of the San Joaquin series are dry-farmed to wheat or barley in extensive tracts. The deeper bodies of the sandy loam and the fine sandy loam are, however, adapted, under careful cultivation and irrigation, to the production of the deciduous fruits, strawberries, bramble berries, and grapes, and in the Sacramento area, California, have attained prominence from the development of the strawberry and Tokay grape industries.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the San Joaquin series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
San Joaquin gravelly loam	California	13,376
sand	do	45,696
sandy loam	do	345,587
fine sandy loam	do	32,128
loam	do	77,504
sandy adobe	do	12,691
clay loam adobe	do	3,776
Total		530,758

Sierra series.

The Sierra series comprises residual soils derived through weathering from granitic rocks, diabase, altered rocks, such as amphibolites, slates, serpentine, and volcanic materials, with a slight admixture of colluvial and alluvial material from the same sources. They are prevailingly of light-red to deep-red color, and generally of somewhat compact structure. They are underlain by the bed rocks, sometimes separated from the overlying soil by a thin stratum of adobelike material. The soils are frequently very shallow and marked by abundant rock outcrops, bowlders, and rough, rocky areas unsuitable for agriculture. The soils of this series occupy rolling and frequently mountainous districts and foothills, usually support a more or less heavy growth of brush and forest trees, and are generally well drained. This series covers large areas of valuable fruit and grazing lands along the western slope and base of the Sierra Nevada Mountains in California. The sandy loam is the leading type of this series, and is devoted extensively to the production of peaches, early cherries, citrus fruits, plums, small fruits, and grapes. The clay loam is also well adapted to peaches, cherries, and other deciduous and small fruits, but the soil in local depressions occurring along ravines is frequently cold and wet, and the type is more extensively devoted to grazing and the production of hay and grains. The sandy adobe and the loam adobe are devoted to dry farming of grains, possess well-developed moisture-retaining properties, and when favorably situated are well adapted to the production of grapes with and without irrigation.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Sierra series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Sierra stony loam	California	30,080
sandy loam	do	64,448
clay loam	do	128,183
sandy adobe	do	13,376
loam adobe	do	10,944
Total		247,031

Sites series.

The Sites series consists of residual and colluvial soils of reddish-gray to dark-brown color, derived from sandstones, shales, conglomerates, and volcanic or altered material, occupying lower rolling foothills and their valley slopes. They are usually underlain at shallow depths by sandstones or shaly sandstones, conglomerates or heavy subsoils. The loam and the clay loam adobe are the important soils of this series. They are productive, but owing to their position are generally unirrigable and adapted only to dry-farming to grain.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Sites series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Sites sandy loam	California	960
loam	do	3,200
clay loam adobe	do	34,176
Total		38,336

Stockton series.

The lighter members of this series are a buff to reddish or chocolate-brown color. The heavier members generally exhibit pronounced adobe structure, are usually free from gravel, and are dark-brown to black in color. The soils are underlain by heavy loams or clay loams of lighter color and are frequently separated from the overlying soil by a thin crust or zone of white calcareous clay hardpan free from alkali. They consist in part of alluvium and in part of wash from more elevated adjacent soils and are generally of older origin than the Hanford series. The heavier members have probably been greatly modified by weathering and by the incorporation and decomposition of organic matter resulting from swamp or marsh conditions. This series occupies extensive areas of the lower, nearly level valley plains traversed by minor foothill streams. The soils are treeless or are marked by occasional groves of valley oaks. The drainage is usually restricted. The heavier members are generally tilled with difficulty, owing to their heavy texture and structure, and are generally devoted to grains and hay. The soils of this series are utilized chiefly for the production of grains and hay crops, although apricots, cherries, and deciduous fruits, vines, and vegetables are grown to some extent upon the fine sandy loam and the silt loam, the latter being well adapted to the production of tree fruits and small fruits.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Stockton series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Stockton fine sandy loam	California	12,832
loam	do	26,176
silt loam	do	16,512
loam adobe	do	2,560
clay loam adobe	do	64,446
clay adobe	do	40,832
Total		163,358

Willows series.

The soils of the Willows series are derived mainly from shale and sandstone rocks, and are deposited along the courses and flood plains of minor intermittent foothill streams traversing valley slopes and plains. They are prevailingly of light yellowish-brown or reddish-brown to dark chocolate-brown color. When well drained and free from alkali they are well adapted to the production of alfalfa, grains, and, with the exception of those of extremely heavy texture, to sugar beets. The clay loam of the Willows series is generally free from alkali, and is usually dry-farmed or used for pasture. In favorable locations it is used for alfalfa and grapes, and under irrigation it produces fair crops of sugar beets and good crops of alfalfa. The clay adobe is retentive of moisture, and when well drained and in proper condition it has a friable structure and is easy to cultivate. It is chiefly dry-farmed, and sometimes it will produce a good crop of alfalfa without irrigation, though with irrigation much better results are secured. Under irrigation, sugar beets and general farm crops do well on this type. The loam of the Willows series is generally dry-farmed, but where irrigation is practiced it is well adapted to alfalfa and vine, tree, and cane fruits. In favorable seasons very fair crops of wheat and barley are produced by dry-farming on the silty clay type, and under irrigation alfalfa and sugar beets do well. The clay type of this series generally contains alkali, and is cultivated with difficulty, owing to poor drainage. It is therefore best adapted to grazing. With proper drainage it may be reclaimed, and would then be suited to various crops.

The acreage of the types so far encountered is as follows:

Area and distribution of the soils of the Willows series.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Willows loam	California	5,568
silty clay loam	do	24,896
clay loam	do	60,480
clay adobe	do	95,488
clay	do	40,640
Total		227,072

Miscellaneous soils of the Pacific coast.

Meadow comprises low-lying, flat, and poorly drained land of variable texture. Frequently of some value for grass and pasturage. Much more of it can be reclaimed by simple methods of drainage, and when this is done excellent results can be secured from a variety of crops.

The Muck and Peat are composed largely of organic matter in various conditions of decay, the Muck representing an advanced stage of change in Peat areas. Of relatively limited extent and poorly drained, these soils are highly valued for their adaptation to special crops, such as celery, onions, peppermint, and cabbage.

The Norman clay adobe with irrigation, drainage, and thorough cultivation should be capable of producing alfalfa, grains, and the general farm crops. At present it is used for grazing and for dry-farming.

The Orland fine sandy loam, occurring in the Sacramento Valley, California, is mainly utilized at present in the production of dry-farmed grains, but should, when placed under irrigation, become of much higher value than at present if devoted to the production of alfalfa, fruits, vegetables, and sugar beets.

The Orland fine sand occurs along streams and is subject to overflow. When protected by dikes it is well adapted to alfalfa, vegetables, and fruits.

The Puget clay and Puget fine sandy loam have deficient drainage, but when drained and protected from overflow truck crops and potatoes are successfully grown.

The Puget silt loam is utilized in the production of potatoes, berries, hops, and oats, and gives promise of becoming a highly prized soil in the small-fruit and vegetable producing industries.

The Salinas gray adobe covers extensive areas in the coastal valleys of California and is utilized mainly in the production of sugar beets or dry-farmed to grains.

Sandhill, Dunesand, and Coastal beach are deep sands of little agricultural value.

The Santiago fine sandy loam covers a considerable area in the Santa Ana area, California, and is devoted principally to dry-farming of wheat and barley.

Tidal swamp and marsh are areas covered with water the greater part of the year and unfit for agriculture.

The other miscellaneous soils are of limited acreage and minor agricultural importance.

The acreage of the types so far encountered is as follows:

Area and distribution of the miscellaneous soils of the Pacific coast.

Soil name.	States in which each type has been found.	Total area.
		Acres.
Bellavista sandy loam	California	3,328
Meadow	do	5,478
Muck and Peat	do	110,163
Norman clay adobe	do	6,208
Orland fine sand	do	1,856
Orland fine sandy loam	do	7,168
Puget clay	Washington	33,984
Puget fine sandy loam	do	18,816
Puget silt loam	do	22,080
Rock outcrop and Riverwash	California	115,393
Salinas gray adobe[a]	do	64,544
Sandhill, Dunesand, and Coastal beach	California, Washington	132,452
Santiago fine sandy loam	California	17,100
Santiago loam	do	1,830
Sheridan sandy loam	do	1,792
Tidal swamp and marsh	California, Washington	31,168
Total		573,680

[a] The soil mapped as Salinas gray adobe in the Sacramento area, California, is Hanford clay adobe.

AREA OF SOILS SURVEYED IN THE SEVERAL STATES.

The following table gives the distribution of the soils surveyed up to January 1, 1908, in the several States:

Area of soils surveyed in the several States, arranged in provinces and series.

ALABAMA.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Atlantic and Gulf Coastal Plains:	*Acres.*	*Acres.*	*Acres.*
Glenn sandy loam		73,600	
loam		35,584	
Greenville fine sandy loam		9,152	
Guin stony sandy loam	28,032		
gravelly sandy loam	69,056		
fine sandy loam	181,824		
		278,912	
Houston clay	450,216		
black clay	26,648		
		476,864	
Lufkin clay		102,016	
Mobile clay		896	
Myatt fine sand	21,376		
fine sandy loam	41,536		
		62,912	
Norfolk gravelly loam	88,832		
coarse sand	100,160		
sand	212,608		
fine sand	61,184		
sandy loam	81,600		
fine sandy loam	305,664		
loam	61,824		
silt loam	17,216		
clay	95,168		
		1,024,256	
Orangeburg sand	66,624		
fine sand	47,616		
sandy loam	136,448		
fine sandy loam	585,536		
clay	175,808		
		1,012,032	
Susquehanna gravelly loam	7,424		
fine sandy loam	147,072		
clay	184,000		
		338,496	
Warsaw sandy loam		33,408	
			3,448,128
River flood plains:			
Chattooga loam		5,696	
Congaree loam	33,856		
clay	16,512		
		50,368	
Huntington silt loam		39,424	
Meadow		294,656	
Ocklocknee sand	960		
fine sandy loam	28,544		
clay	29,824		
		59,328	
Swamp		8,192	
Wabash silt loam	49,792		
clay	50,624		
		100,416	
Waverly loam	100,288		
clay	11,840		
		112,128	
			670,208
Piedmont Plateau:			
Cecil stony loam	69,056		
stony clay	17,856		
sandy loam	155,584		
clay	9,536		
		252,032	
Rough stony land		4,928	
			256,960

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

ALABAMA—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Appalachian Mountains and Plateau:	*Acres.*	*Acres.*	*Acres.*
Chandler stony loam		1,664	
Dekalb stony loam	37,120		
sandy loam	351,168		
fine sandy loam	95,744		
silt loam	17,280		
clay	77,952		
		579,264	
Lickdale stony loam		4,416	
Montevallo stony loam		4,032	
Rough stony land		49,344	
Talladega stony loam		15,552	
slate loam		95,552	
Upshur sandy loam	8,896		
loam	14,720		
		23,616	
			773,440
Limestone valleys and uplands:			
Clarksville stony loam	432,128		
gravelly sandy loam	5,376		
fine sandy loam	1,856		
loam	6,272		
silt loam	163,840		
		609,472	
Cumberland fine sandy loam		4,864	
Decatur stony loam	85,696		
loam	25,664		
clay loam	56,064		
		167,424	
Guthrie silt loam		320	
clay		15,424	
Hagerstown stony loam	41,984		
stony clay	6,848		
sandy loam	8,064		
loam	221,568		
clay	12,992		
		291,456	
			1,088,960
Total for State			6,237,696

ARIZONA.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Arid Southwest:			
Gila fine sand	27,144		
fine sandy loam	43,794		
loam	35,136		
silt loam	9,408		
clay loam	23,424		
clay	13,655		
		152,561	
Glendale clay loam		52,040	
Rough stony land and Riverwash		8,140	
Yuma sand		94,400	
			307,141
Pacific coast:			
Maricopa gravelly loam	51,066		
sand	20,480		
sandy loam	10,368		
fine sandy loam	106,906		
loam	33,514		
silt loam	11,648		
clay loam	8,713		
		242,695	
			242,695
Total for State			549,836

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

ARKANSAS.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Atlantic and Gulf Coastal Plains:	*Acres.*	*Acres.*	*Acres.*
Acadia silt loam		136,512	
Crowley silt loam		232,960	
Morse clay		5,760	
Orangeburg fine sandy loam		224,640	599,872
River flood plains:			
Biscoe silt loam		12,992	
Calhoun clay		12,672	
Collins silt loam		8,576	
Miller fine sand	34,688		
fine sandy loam	28,544		
clay	110,656	173,888	
Meadow		1,536	
Swamp		2,240	
Wabash fine sand	4,480		
fine sandy loam	10,112		
loam	6,464		
silt loam	48,192		
clay loam	11,584		
clay	23,040	103,872	
Waverly silt loam	44,672		
clay	98,688	143,360	459,136
Appalachian Mountains and Plateau:			
Conway silt loam		38,912	
Fayetteville stony loam	118,400		
fine sandy loam	17,216		
loam	44,352	179,968	
Rough stony land		104,000	
Upshur stony loam	23,232		
fine sandy loam	17,472		
loam	12,160	52,864	375,744
Limestone valleys and uplands:			
Clarksville stony loam	145,472		
silt loam	90,880	236,352	
Guthrie clay		27,904	264,256
Residual soils of the western prairie:			
Gasconade silt loam			14,720
Total for State			1,713,728

CALIFORNIA.

Arid Southwest:	*Acres.*	*Acres.*	*Acres.*
Gila fine sand	1,088		
loam	44,096		
silt loam	3,264		
clay loam	960		
clay	4,096	53,504	
Imperial sand	1,792		
sandy loam	126,656		
clay loam	341,056		
clay	46,912	516,416	
Indio gravelly loam	43,328		
sand	50,112		
fine sand	36,032		
fine sandy loam	42,432	171,904	741,824
Pacific coast:			
Anderson gravelly loam	14,528		
fine sandy loam	3,520	18,048	

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

CALIFORNIA—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Pacific coast—Continued.	*Acres.*	*Acres.*	*Acres.*
Bellavista sandy loam		3,328	
Dunesand		129,828	
Fresno sand	193,526		
fine sand	8,128		
sandy loam	5,952		
fine sandy loam	90,975		
loam	5,824		
		304,405	
Hanford gravel	4,544		
sand	224,680		
fine sand	118,338		
sandy loam	19,860		
fine sandy loam	151,194		
silt loam	73,137		
clay loam	17,896		
clay adobe	12,672		
		622,321	
Maricopa gravelly sand	194,886		
gravelly loam	47,160		
sand	7,838		
sandy loam	37,312		
fine sandy loam	5,952		
		293,148	
Meadow		5,478	
Norman clay adobe		6,208	
Orland fine sand		1,856	
Orland fine sandy loam		7,168	
Oxnard gravelly loam	16,270		
sand	56,520		
sandy loam	75,600		
fine sandy loam	22,848		
loam	19,812		
silt loam	31,240		
clay loam	30,574		
clay loam adobe	134,598		
		387,462	
Peat		110,163	
Placentia sandy adobe	36,454		
sandy loam	66,688		
fine sandy loam	354,333		
loam	32,904		
loam adobe	16,320		
clay loam	2,816		
clay loam adobe	8,916		
		518,431	
Redding gravelly loam	57,216		
loam	14,272		
		71,488	
Rough stony land and Riverwash		115,393	
Sacramento gravelly sandy loam	20,224		
fine sandy loam	4,224		
loam	14,144		
silt loam	17,408		
silty clay loam	50,368		
clay loam	41,088		
silty clay	26,368.		
		173,824	
Salinas gray adobe		64,544	
San Joaquin gravelly loam	13,376		
sand	45,696		
sandy adobe	12,691		
sandy loam	345,587		
fine sandy loam	32,128		
loam	77,504		
clay loam adobe	3,776		
		530,758	
Santiago fine sandy loam		17,100	
Santiago loam		1,830	
Sheridan sandy loam		1,792	
Sierra stony loam	30,080		
sandy adobe	13,376		
sandy loam	64,448		
loam adobe	10,944		
clay loam	128,183		
		247,031	

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

CALIFORNIA—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Pacific coast—Continued.	*Acres.*	*Acres.*	*Acres.*
Sites sandy loam	960		
loam	3,200		
clay loam adobe	34,176		
		38,336	
Stockton fine sandy loam	12,832		
loam	26,176		
loam adobe	2,560		
silt loam	16,512		
clay loam adobe	64,446		
clay adobe	40,832		
		163,358	
Tidal swamp and marsh		30,848	
Willows loam	5,568		
silty clay loam	24,896		
clay loam	60,480		
clay	40,640		
clay adobe	95,488		
		227,072	
			4,091,218
Total for State			4,833,042

COLORADO.

Glacial and loessial:	*Acres.*	*Acres.*	*Acres.*
Marshall silt loam			236,288
Rocky Mountain valleys and plains:			
Billings fine sandy loam	26,944		
loam	41,984		
silt loam	9,664		
clay loam	16,128		
clay	5,760		
		100,480	
Colorado gravelly loam	33,408		
sand	128,576		
sandy loam	156,096		
fine sandy loam	196,480		
loam	78,784		
loam adobe	42,880		
clay loam	832		
		637,056	
Dunesand		3,328	
Fort Collins loam		14,144	
Fruita fine sandy loam	3,968		
loam	512		
		4,480	
Laurel fine sand	8,960		
sandy loam	72,640		
loam	37,760		
clay loam	23,104		
		142,464	
Mesa fine sandy loam	34,432		
clay loam	2,240		
clay	22,464		
		59,136	
Riverwash		12,800	
San Luis sand	136,960		
sandy loam	196,992		
loam	9,088		
		343,040	
Swamp		640	
			1,317,568
Total for State			1,553,856

CONNECTICUT.

River flood plains:	*Acres.*	*Acres.*	*Acres.*
Meadow		33,814	
Swamp		24,912	
			58,726

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

CONNECTICUT—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Piedmont Plateau:	*Acres.*	*Acres.*	*Acres.*
Penn stony loam			85,080
Glacial and loessial:			
Holyoke stony loam			5,056
Glacial lake and river terraces:			
Elmwood loam		12,280	
Enfield sandy loam		32,534	
Manchester sandy loam		19,520	
Merrimac gravelly sandy loam	4,096		
coarse sand	19,196		
coarse sandy loam	18,816		
sandy loam	54,900		
		97,008	
Podunk fine sandy loam		2,016	
Suffield clay		11,154	
			174,512
Total for State			323,374

DELAWARE.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Atlantic and Gulf Coastal Plains:	*Acres.*	*Acres.*	*Acres.*
Coastal beach		64	
Elkton silt loam		6,016	
Norfolk sand	5,632		
loam	66,752		
silt loam	32,960		
		105,344	
Portsmouth sand	640		
sandy loam	50,304		
		50,944	
Tidal swamp and marsh		30,784	
			193,152
River flood plains:			
Meadow		4,096	
Swamp		3,712	
			7,808
Total for State			200,960

FLORIDA.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Atlantic and Gulf Coastal Plains:	*Acres.*	*Acres.*	*Acres.*
Gadsden sand	49,856		
sandy loam	6,592		
		56,448	
Gainesville sand		7,744	
Leon sand		61,376	
Leon fine sand		17,728	
Muck		128	
Myatt fine sandy loam		5,696	
Norfolk sand	636,736		
fine sand	48,448		
sandy loam	175,424		
fine sandy loam	214,912		
very fine sandy loam	768		
loam	17,536		
		1,093,824	
Orangeburg sand	51,968		
sandy loam	17,024		
fine sandy loam	140,736		
loam	1,280		
		211,008	
Portsmouth sand	40,064		
fine sand	93,824		
sandy loam	40,384		
fine sandy loam	6,016		
		180,288	
Sandhill and Coastal beach		52,928	
Swamp and Marsh		60,352	
			1,747,520

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

FLORIDA—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
River flood plains:	*Acres.*	*Acres.*	*Acres.*
Meadow		137,152	
Ocklocknee clay		3,712	
Swamp		2,816	
			143,680
Total for State			1,891,200

GEORGIA.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Atlantic and Gulf Coastal Plains:	*Acres.*	*Acres.*	*Acres.*
Gadsden sand		7,488	
Norfolk coarse sand	12,416		
sand	266,688		
fine sand	27,776		
sandy loam	160,576		
fine sandy loam	128,064		
clay	640		
		596,160	
Orangeburg sand	22,592		
fine sandy loam	61,376		
clay	31,168		
		115,136	
Portsmouth sand	3,456		
fine sand	205,568		
fine sandy loam	43,840		
		252,864	
Sandhill		5,888	
Swamp		26,944	
			1,004,480
River flood plains:			
Meadow		105,506	
Ocklocknee clay		832	
			106,338
Piedmont Plateau:			
Cecil sand	448		
sandy loam	105,134		
clay	332,620		
		438,202	438,202
Appalachian Mountains and Plateau:			
Porters stony loam			2,020
Total for State			1,551,040

IDAHO.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Northwestern intermountain region:	*Acres.*	*Acres.*	*Acres.*
Boise loam		61,960	
Boise silt loam		95,850	
Deer Flat fine sandy loam		45,380	
Gallatin fine sandy loam	35,212		
loam	241,216		
silt loam	17,436		
		293,864	
Meadow		1,600	
Riverwash		1,792	
Yakima sand	48,448		
fine sand	17,430		
sandy loam	29,760		
fine sandy loam	31,872		
loam	18,944		
silt loam	172,992		
		319,446	
			819,892
Total for State			819,892

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

ILLINOIS.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
River flood plains:	*Acres.*	*Acres.*	*Acres.*
Lintonia loam		5,696	
Meadow		47,872	
Wabash loam	29,056		
silt loam	125,276		
clay	54,656		
		208,988	
Waverly fine sandy loam	1,344		
silt loam	137,600		
clay loam	128		
		139,072	
Yazoo sandy loam		15,104	
Yazoo loam		7,040	
			423,772
Glacial and loessial:			
Marion silt loam		519,488	
Marshall sandy loam	84,160		
loam	17,984		
silt loam	1,450,560		
black clay loam	224,384		
		1,777.088	
Memphis silt loam		305,856	
Miami gravel	6,272		
fine sand	36.544		
silt loam	616.064		
		658,880	
Rough stony land		23,360	
			3,284,672
Glacial lake and river terraces:			
Muck and Peat		3,840	
Sioux sandy loam	38,528		
loam	32,512		
silt loam	25,600		
		96,640	
			100,480
Total for State			3,808,924

INDIANA.

Atlantic and Gulf Coastal Plains:	*Acres.*	*Acres.*	*Acres.*
Norfolk fine sandy loam		22,848	
			22,848
River flood plains:			
Griffin clay		1,600	
Huntington fine sandy loam	13,696		
loam	31,040		
silt loam	16,512		
		61,248	
Lintonia loam		9,408	
Meadow		17,600	
Riverwash		1,024	
Wabash sandy loam	2,624		
fine sandy loam	15,296		
silt loam	26,624		
		44,544	
Waverly fine sandy loam	9,920		
loam	8,320		
silt loam	62,592		
clay loam	44,800		
clay	39,040		
		164,672	
Yazoo sandy loam		2,752	
			302,848
Appalachian Mountains and Plateau:			
Dekalb silt loam			22,080
Glacial and loessial:			
Bloomfield sandy loam		10,944	
Madison loam		2,240	
Marshall sand	20,672		
fine sand	9,792		
sandy loam	77,184		
fine sandy loam	54,144		
loam	275.392		
silt loam	142,854		
black clay loam	41,408		
		621,446	

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

INDIANA—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Glacial and loessial—Continued.	*Acres.*	*Acres.*	*Acres.*
Miami gravelly sandy loam	2,240		
gravelly loam	576		
sand	36,032		
sandy loam	512		
fine sand	35,520		
fine sandy loam	4,608		
loam	26,688		
silt loam	504,832		
clay loam	424,704		
		1,035,712	
Rough stony land		18,432	
Scottsburg silt loam		37,184	
Volusia silt loam		46,912	
			1,772,870
Glacial lake and river terraces:			
Clyde fine sand	61,056		
sandy loam	11,712		
loam	960		
clay	6,144		
		79,872	
Marco fine sandy loam		3,392	
Marco clay loam		3,200	
Muck and Peat		40,832	
Newton fine sand		5,888	
Sioux sandy loam	9,344		
loam	896		
silt loam	570		
		10,810	
Swamp		3,648	
			147,642
Total for State			2,268,288

IOWA.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
River flood plains:	*Acres.*	*Acres.*	*Acres.*
Meadow		22,592	
Wabash silt loam		91,520	
			114,112
Glacial and loessial:			
Marshall sand	1,024		
fine sand	3,072		
loam	547,648		
silt loam	308,288		
clay loam	75,840		
black clay loam	25,984		
		961,856	
Miami fine sand	3,968		
sandy loam	15,040		
silt loam	244,736		
clay loam	13,376		
		277,120	
Rough stony land		55,744	
			1,294,720
Glacial lake and river terraces:			
Muck		12,096	
Sioux sandy loam		32,768	
			44,864
Total for State			1,453,696

KANSAS.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Atlantic and Gulf Coastal Plains:	*Acres.*	*Acres.*	*Acres.*
Houston clay			35,456
River flood plains:			
Neosho silt loam		30,739	
Wabash silt loam	85,184		
silt clay	4,992		
clay	37,107		
		127,283	
Yazoo sandy loam		909	
Yazoo loam		48,883	
			207,814

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

KANSAS—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Glacial and loessial:	*Acres.*	*Acres.*	*Acres.*
Marshall gravelly loam	10,176		
sandy loam	2,240		
silt loam	515,840		
		528,256	
Miami sand	19,392		
fine sand	15,744		
		35,136	
Rough stony land		17,088	
			580,480
Residual soils of the western prairie:			
Crawford gravelly loam	5,165		
silt loam	211,559		
clay	68,544		
		285,268	
Derby loam		20,416	
Oswego fine sandy loam	25,293		
silt loam	462,848		
		488,141	
Rock outcrop and Rough stony land		120,793	
Sedgwick black clay loam		5,568	
			920,186
Rocky Mountain valleys and plains:			
Colorado sand	10,944		
sandy loam	27,200		
loam	47,040		
		85,184	
Dunesand		83,200	
Finney sandy loam	6,272		
clay	2,240		
		8,512	
Laurel fine sand	2,112		
sandy loam	16,000		
fine sandy loam	13,888		
loam	54,272		
loam adobe	1,472		
silt loam	17,600		
		105,344	
Rough stony land		8,768	
			291,008
Total for State			2,034,944

KENTUCKY.

Atlantic and Gulf Coastal Plains:	*Acres.*	*Acres.*	*Acres.*
Leonardtown loam		320	
Norfolk fine sandy loam	3,008		
loam	896		
		3,904	
Portsmouth silt loam		896	
			5,120
River flood plains:			
Lintonia loam		17,984	
Meadow		832	
Muck		320	
Riverwash		128	
Wabash silt loam	45,440		
		45,440	
Waverly fine sandy loam	3,072		
silt loam	5,824		
clay	38,016		
		46,912	
			111,616
Appalachian Mountains and Plateau:			
Dekalb shale loam	18,880		
fine sandy loam	832		
loam	20,800		
silt loam	120,832		
		161,344	
Rough stony land		3,904	
			165,248
Limestone valleys and uplands:			
Clarksville silt loam	232,832		
clay loam	9,408		
		242,240	

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

KENTUCKY—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Limestone valleys and uplands—Continued.	*Acres.*	*Acres.*	*Acres.*
Cumberland loam		4,288	
Guthrie clay		4,480	
Hagerstown stony clay	33,792		
loam	208,256		
clay	261,568		
		503,616	
			754,624
Glacial and loessial:			
Memphis silt loam		139,776	
Miami silt loam		154,176	
			293,952
Total for State			1,330,560

LOUISIANA.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Atlantic and Gulf Coastal Plains:	*Acres.*	*Acres.*	*Acres.*
Acadia silt loam		89,280	
Amite sandy loam		7,232	
Amite loam		16,320	
Caddo fine sandy loam		142,528	
Calcasieu fine sand		13,970	
Calcasieu fine sandy loam		5,500	
Calcasieu loam		51,280	
Crowley silt loam		244,160	
Greenville gravelly sandy loam		10,752	
Greenville loam		2,048	
Hammond silt loam		70,976	
Houston clay		1,728	
Lacasine clay loam		3,470	
Lake Charles fine sandy loam		143,924	
Lake Charles loam		6,378	
Landry silt loam		37,696	
Lufkin clay		5,440	
Monroe silt loam		236,096	
Morse clay		1,664	
Myatt fine sandy loam		8,064	
Norfolk sand	1,600		
fine sand	23,040		
fine sandy loam	550,720		
		575,360	
Orangeburg sand	4,544		
fine sand	54,336		
sandy loam	1,280		
fine sandy loam	300,032		
		360,192	
Peat		59,200	
Susquehanna fine sandy loam	348,544		
clay loam	14,080		
clay	45,696		
		408,320	
Swamp, Tidal swamp and marsh		10,304	
			2,511,882
River flood plains:			
Meadow		316,288	
Miller fine sand	16,960		
fine sandy loam	110,976		
silt loam	23,296		
clay	99,200		
		250,432	
Muck		21,056	
Sharkey clay		243,648	
Swamp		13,248	
Wabash clay	41,088		
		41,088	
Yazoo sandy loam		43,136	
Yazoo loam		19,584	
			948,480
Glacial and loessial:			
Marshall silt loam		16,640	
Memphis silt loam		219,200	
			235,840
Total for State			3,696,202

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

MARYLAND.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Atlantic and Gulf Coastal Plains:	*Acres.*	*Acres.*	*Acres.*
Coastal beach		8,064	
Collington sandy loam		23,260	
Elkton sandy loam	9,280		
loam	2,624		
silt loam	140,524		
		152,428	
Leonardtown loam		152,930	
Norfolk gravel	123,740		
coarse sand	65,370		
sand	234,272		
fine sand	58,590		
fine sandy loam	23,380		
loam	88,078		
silt loam	196,050		
		789,480	
Portsmouth sand	41,024		
sandy loam	37,696		
loam	2,944		
		81,664	
Sassafras gravelly loam	2,880		
sand	29,696		
loamy sand	52,992		
sandy loam	160,576		
fine sandy loam	18,496		
loam	101,760		
silt loam	130,944		
		497,344	
Susquehanna clay loam	16,850		
clay	38,250		
		55,100	
Swamp, Tidal swamp and marsh		69,200	
			1,829,470
River flood plains:			
Meadow		176,620	
Swamp		2,200	
			178,820
Piedmont Plateau:			
Cardiff slate loam		1,690	
Cecil clay		52,838	
Chester mica loam	51,938		
loam	171,624		
		223,562	
Conowingo barrens		5,280	
Conowingo clay		9,510	
Loudoun sandy loam		768	
Penn gravelly loam	192		
loam	1,344		
clay	2,240		
		3,776	
			297,424
Appalachian Mountains and Plateau:			
Dekalb stony loam	1,600		
shale loam	192		
		1,792	
			1,792
Total for State			2,307,506

MASSACHUSETTS.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
River flood plains:	*Acres.*	*Acres.*	*Acres.*
Meadow		41,038	
Swamp		14,774	
			55,812
Piedmont Plateau:			
Penn stony loam			24,036
Glacial and loessial:			
Bernardstown loam		16,064	
Holyoke stony loam		191,762	
			207,826
Glacial lake and river terraces:			
Elmwood loam		6,598	
Enfield sandy loam		13,928	
Manchester sandy loam		24,640	

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

MASSACHUSETTS—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Glacial lake and river terraces—Continued.	*Acres.*	*Acres.*	*Acres.*
Merrimac gravelly sandy loam	55,188		
coarse sandy loam	9,088		
coarse sand	52,812		
sandy loam	40,404		
		157,492	
Podunk fine sandy loam		15,268	
Suffield clay		12,456	
			230,382
Total for State			518,056

MICHIGAN.

River flood plains:	*Acres.*	*Acres.*	*Acres.*
Meadow		53,462	
Wabash loam		1,152	
			54,614
Limestone valleys and uplands:			
Fort Payne sandy loam			7,936
Glacial and loessial:			
Marshall loam	20,544		
black clay loam	13,056		
		33,600	
Miami stony sand	5,622		
stony loam	80,310		
gravelly sand	57,642		
gravelly sandy loam	27,840		
gravelly loam	1,088		
sand	474,824		
fine sand	64,460		
sandy loam	249,780		
fine sandy loam	119,360		
loam	103,296		
clay loam	271,242		
		1,455,464	
Rough stony land		17,344	
			1,506,408
Glacial lake and river terraces:			
Clyde stony sandy loam	8,000		
gravelly sand	24,656		
sand	67,400		
sandy loam	98,304		
fine sandy loam	40,704		
loam	386,476		
silt loam	3,904		
clay	26,560		
		656,004	
Dunesand		10,554	
Elmwood loam		3,810	
Muck		143,658	
Saginaw sandy loam		14,272	
Saugatuck sand		24,120	
Superior clay		704	
Swamp and Marsh		2,752	
			855,874
Total for State			2,424,832

MINNESOTA.

River flood plains:	*Acres.*	*Acres.*	*Acres.*
Meadow		24,960	
Wabash fine sandy loam	14,528		
loam	3,968		
silt loam	13,312		
		31,808	
			56,768
Glacial and loessial:			
Barnum stony loam		8,704	
Barnum loam		2,496	

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

MINNESOTA—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Glacial and loessial—Continued.	*Acres.*	*Acres.*	*Acres.*
Judson loam		3,968	
Marshall gravel	1,216		
gravelly loam	960		
fine sand	15,872		
sandy loam	4,480		
fine sandy loam	13,824		
loam	117,120		
silt loam	128,704		
clay loam	185,152		
black clay loam	29,760		
		497,088	
Miami stony loam	50,560		
gravelly sandy loam	5,184		
sand	17,408		
fine sand	1,920		
sandy loam	54,784		
		129,856	
Rock outcrop and Rough stony land		19,264	
			661,376
Glacial lake and river terraces:			
Benoit fine sandy loam		4,032	
Benoit loam		31,360	
Dunesand		1,024	
Fargo fine sandy loam	93,312		
silt loam	20,032		
clay loam	344,576		
clay	27,968		
		485,888	
Mankato sand		4,032	
Mankato sandy loam		2,816	
Mankato loam		1,600	
McLeod sand		4,288	
Muck and Peat		33,344	
Sioux gravelly sandy loam		24,448	
Superior silt loam	16,192		
clay	43,392		
		59,584	
			652,416
Total for State			1,370,560

MISSISSIPPI.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Atlantic and Gulf Coastal Plains:	*Acres.*	*Acres.*	*Acres.*
Gadsden loam		14,592	
Guin fine sandy loam		176,192	
Houston chalk	8,064		
clay	38,400		
		46,464	
Lufkin silt loam	55,808		
clay	71,040		
		126,848	
Monroe silt loam		64,896	
Montrose sandy loam	20,928		
clay	43,840		
		64,768	
Myatt fine sandy loam	6,144		
clay loam	4,096		
		10,240	
Norfolk gravelly loam	48,768		
coarse sand	448		
sand	77,568		
fine sand	57,216		
sandy loam	16,128		
fine sandy loam	374,464		
loam	83,264		
		657,856	
Oktibbeha fine sandy loam	17,344		
silt loam	13,824		
clay loam	15,360		
clay	25,920		
		72,448	

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

MISSISSIPPI—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Atlantic and Gulf Coastal Plains Continued.	*Acres.*	*Acres.*	*Acres.*
Orangeburg sand	6,656		
fine sand	2,304		
sandy loam	81,856		
fine sandy loam	166,400		
loam	1,984		
clay	98,368		
		357,568	
Portsmouth loam		3,328	
Susquehanna fine sandy loam	6,080		
silt loam	9,984		
clay	31,360		
		47,424	
			1,642,624
River flood plains:			
Catalpa silt loam		5,056	
Congaree loam		53,760	
Lintonia loam		54,452	
Meadow		131,992	
Neuse clay		13,120	
Ocklocknee loam	103,360		
clay loam	13,632		
clay	55,552		
		172,544	
Sharkey clay		333,820	
Swamp		3,072	
Wabash clay		90,456	
Waverly fine sandy loam	3,840		
loam	8,960		
silt loam	49,152		
clay	7,360		
		69,312	
Yazoo sandy loam		35,182	
Yazoo loam		36,368	
			999,134
Glacial and loessial:			
Memphis silt loam			775,866
Total for State			3,417,624

MISSOURI.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
River flood plains:	*Acres.*	*Acres.*	*Acres.*
Jackson loam		2,304	
Meadow		40,000	
Riverwash		1,856	
Wabash loam	11,904		
silt loam	186,944		
clay	59,904		
		258,752	
Waverly silt loam	49,664		
clay loam	23,296		
		72,960	
Yazoo loam		30,912	
			406,784
Appalachian Mountains and Plateau:			
Dekalb fine sandy loam			3,584
Limestone valleys and uplands:			
Clarksville silt loam	365,376		
stony loam	1,044,160		
		1,409,536	
Rough stony land		3,200	
			1,412,736
Glacial and loessial:			
Marion silt loam		175,552	
Marshall silt loam		306,816	
Memphis silt loam		5,184	
Miami fine sand	640		
silt loam	74,432		
		75,072	
Rough stony land		28,160	
Shelby sand		448	
Shelby loam		410,368	
Shelby silt loam		402,112	
			1,403,712

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

MISSOURI—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
	Acres.	*Acres.*	*Acres.*
Glacial lake and river terraces:			
Sioux sandy loam			320
Residual soils of the western prairie:			
Gasconade silt loam			1,600
Total for State			3,228,736

MONTANA.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Northwestern intermountain region:	*Acres.*	*Acres.*	*Acres.*
Bozeman silt loam		76,608	
Bridger gravelly loam	12,544		
clay loam	1,472	14,016	
Gallatin gravelly loam	32,576		
fine sandy loam	6,464		
silt loam	23,808		
clay loam	896	63,744	
Yakima silt loam		53,824	208,192
Rocky Mountain valleys and plains:			
Billings gravelly loam	11,776		
fine sandy loam	13,568		
clay loam	14,144		
clay	17,088	56,576	
Laurel sandy loam		8,832	
Swamp		3,008	68,416
Total for State			276,608

NEBRASKA.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
River flood plains:	*Acres.*	*Acres.*	*Acres.*
Meadow		28,544	
Muck		3,264	
Sarpy clay loam		2,816	
Wabash fine sandy loam	22,144		
silt loam	131,264		
clay	3,648	157,056	191,680
Glacial and loessial:			
Marshall fine sandy loam	15,424		
fine sand	21,440		
loam	142,144		
silt loam	964,864	1,143,872	
Miami sand	29,440		
fine sand	56,576		
silt loam	69,696	155,712	1,299,584
Glacial lake and river terraces:			
Sioux sandy loam	29,184		
fine sandy loam	60,352	89,536	89,536
Rocky Mountain valleys and plains:			
Dunesand		161,664	
Finney fine sandy loam	40,128		
loam	11,008	51,136	
Gannett fine sand		8,448	
Lancaster fine sandy loam		2,368	
Laurel gravelly loam	16,448		
fine sand	5,440		
sandy loam	10,048		
fine sandy loam	5,760		
loam	24,768	62,464	

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

NEBRASKA—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Rocky Mountain valleys and plains—Continued.	*Acres.*	*Acres.*	*Acres.*
Meadow		46,272	
North Platte loam		23,936	
Osgood fine sandy loam		16,320	
Rough stony land and Riverwash		40,000	
			412,608
Total for State			1,993,408

NEW HAMPSHIRE.

River flood plains:	*Acres.*	*Acres.*	*Acres.*
Meadow			14,848
Glacial and loessial:			
Gloucester stony sandy loam		67,904	
Gloucester stony loam		80,192	
Rock outcrop and Rough stony land		323,008	
			471,104
Glacial lake and river terraces:			
Merrimac coarse sand	13,824		
sand	26,560		
gravelly sandy loam	50,240		
		90,624	
Podunk fine sandy loam		12,928	
Podunk silt loam		960	
			104,512
Total for State			590,464

NEW JERSEY.

Atlantic and Gulf Coastal Plains:	*Acres.*	*Acres.*	*Acres.*
Alloway clay		22,484	
Collington sandy loam		87,626	
Elkton silt loam		11,240	
Norfolk gravel	192		
coarse sand	18,792		
sand	129,290		
fine sand	31,134		
sandy loam	25,430		
silt loam	194,412		
		399,250	
			520,600
River flood plains:			
Meadow			95,770
Piedmont Plateau:			
Cecil stony loam		13,952	
Penn stony loam	5,632		
sandy loam	10,816		
loam	171,712		
		188,160	
			202,112
Total for State			818,482

NEW MEXICO.

Arid Southwest:	*Acres.*	*Acres.*	*Acres.*
Gila fine sand		2,810	
Gypsum		11,630	
Meadow		7,940	
Pecos conglomerate		11,680	
Pecos sandy loam		36,310	
Roswell fine sandy loam		9,090	
Roswell loam		2,730	
Total for State			82,190

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

NEW YORK.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Atlantic and Gulf Coastal Plains:	*Acres.*	*Acres.*	*Acres.*
Coastal beach		12,224	
Hempstead loam		53,824	
Norfolk gravel	3,328		
coarse sand	1,856		
sand	77,120		
coarse sandy loam	64,896		
loam	100,096		
		247,296	
Tidal swamp and marsh		52,800	
			366,144
River flood plains:			
Huntington loam	24,640		
silt loam	11,200		
		35,840	
Meadow		100,670	
Wabash loam		39,872	
			176,382
Appalachian Mountains and Plateau:			
Dekalb clay		21,860	
Upshur clay		7,936	
			29,796
Glacial and loessial:			
Allis shale loam		2,368	
Allis clay		2,304	
Cassadaga sand		1,660	
Dover fine sandy loam		8,512	
Dover loam		28,800	
Dutchess stony loam		51,776	
Dutchess slate loam		94,144	
Dutchess silt loam		117,184	
Gloucester stony loam		8,256	
Gloucester loam		10,752	
Madeland		1,024	
Miami stony sand	5,376		
stony sandy loam	163,008		
stony loam	509,056		
fine sand	31,936		
fine sandy loam	6,848		
		716,224	
Rhinebeck loam		1,088	
Rock outcrop and Rough stony land		140,736	
Volusia stony loam	12,352		
gravelly loam	4,608		
loam	291,234		
silt loam	444,608		
clay loam	5,952		
		758,754	
			1,943,582
Glacial lake and river terraces:			
Clyde fine sand	320		
fine sandy loam	20,224		
loam	55,360		
clay	18,752		
		94,656	
Dunkirk stony clay	35,072		
gravel	4,840		
gravelly sandy loam	31,004		
gravelly loam	98,432		
shale loam	14,592		
fine sand	10,944		
sandy loam	4,480		
fine sandy loam	105,674		
loam	144,832		
silt loam	94,272		
clay loam	107,264		
clay	121,666		
		773,072	
Hudson sandy loam	1,856		
fine sandy loam	6,400		
loam	3,904		
clay loam	9,984		
		22,144	
Lockport clay		6,656	
Merrimac gravelly loam	41,216		
gravelly sandy loam	9,600		
loam	1,600		
		52,416	

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

NEW YORK—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Glacial lake and river terraces—Continued.	*Acres.*	*Acres.*	*Acres.*
Muck and Peat		45,568	
Podunk fine sandy loam		192	
Swamp		14,272	
Tonawanda loam		15,168	
Vergennes stony loam	2,752		
gravelly loam	2,944		
fine sand	6,272		
sandy loam	128		
loam	2,048		
clay	27,904		
		42,048	
Warners loam		128	
			1,066,320
Total for State			3,582,224

NORTH CAROLINA.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Atlantic and Gulf Coastal Plains:	*Acres.*	*Acres.*	*Acres.*
Muck		6,230	
Norfolk gravel	11,410		
coarse sand	384		
sand	88,958		
fine sand	266,304		
sandy loam	362,524		
fine sandy loam	592,388		
silt loam	12,992		
clay	9,600		
		1,344,560	
Orangeburg fine sandy loam		7,616	
Portsmouth sand	49,068		
fine sand	28,608		
sandy loam	89,124		
fine sandy loam	150,436		
loam	105,152		
silt loam	126,272		
		548,680	
Sandhill and Coastal beach		23,432	
Susquehanna gravelly loam		14,330	
Swamp, Tidal swamp and marsh		388,650	
			2,333,498
River flood plains:			
Meadow		84,010	
Neuse clay		4,832	
Swamp		38,288	
Toxaway fine sandy loam		22,976	
Toxaway loam		11,328	
			161,434
Piedmont Plateau:			
Cecil sand	131,860		
sandy loam	546,528		
loam	3,370		
silt loam	7,860		
clay	516,654		
		1,206,272	
Conowingo clay		29,952	
Iredell clay loam		41,100	
			1,277,324
Appalachian Mountains and Plateau:			
Dekalb stony loam		7,488	
Porters stony loam	38,242		
sand	86,336		
sandy loam	333,888		
loam	402,496		
black loam	116,544		
clay	175,232		
		1,152,738	
Rock outcrop		13,056	
			1,173,282
Total for State			4,945,538

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

NORTH DAKOTA.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
	Acres.	*Acres.*	*Acres.*
River flood plains:			
Carrington clay loam		6,272	
Meadow		33,472	
Riverwash		17,408	
Wabash loam	46,208		
clay	3,328		
		49,536	
			106,688
Glacial and loessial:			
Hobart clay		6,208	
Marshall stony loam	75,840		
gravel	1,344		
gravelly loam	71,616		
fine sand	4,096		
fine sandy loam	27,776		
loam	420,992		
silt loam	281,408		
black clay loam	124,352		
clay loam	268,800		
clay	76,800		
		1,353,024	
Wheatland sand		29,504	
Wheatland sandy loam		16,768	
Williams stony loam		69,888	
Williams loam		272,256	
			1,747,648
Glacial lake and river terraces:			
Bearden loam		3,584	
Clyde fine sandy loam	79,680		
loam	94,784		
clay	18,880		
		193,344	
Dunesand		11,968	
Fargo sand	22,016		
fine sand	19,904		
fine sandy loam	40,192		
loam	20,800		
silt loam	7,040		
clay	42,368		
		152,320	
McLeod sand		33,728	
Muck		6,592	
Sioux gravelly loam	30,400		
fine sandy loam	5,632		
loam	15,744		
clay	2,432		
		54,208	
Williston gravelly sandy loam		12,352	
Williston sandy loam		3,584	
			471,680
Rocky Mountain valleys and plains:			
Epping clay		384	
Finney clay		1,024	
Laurel fine sandy loam	1,984		
loam	1,216		
silt loam	1,280		
clay loam	3,904		
clay	6,656		
		15,040	
Morton stony loam	48,128		
fine sand	4,352		
fine sandy loam	117,952		
loam	163,456		
silt loam	104,576		
clay loam	17,024		
clay	704		
gumbo	8,448		
		464,640	
Rough broken land (Bad Lands) and Riverwash		22,720	
Scoria gravel		25,920	
Wade fine sandy loam	12,608		
loam	8,576		
silt loam	28,352		
clay	8,256		
		57,792	
			587,520
Total for State			2,913,536

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

OHIO.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
River flood plains:	*Acres.*	*Acres.*	*Acres.*
Huntington silt loam		16,704	
Meadow		20,064	
Wabash sandy loam	4,000		
loam	95,920		
clay	1,216		
		101,136	
Waverly clay		25,408	
Wheeling gravelly loam	7,680		
fine sand	640		
fine sandy loam	1,984		
silt loam	2,432		
		12,736	
			176,048
Appalachian Mountains and Plateau:			
Dekalb sandy loam	12,096		
silt loam	425,472		
clay	9,728		
		447,296	
Meigs clay loam		114,432	
Rough stony land		4,928	
Upshur clay		17,216	
			583,872
Glacial and loessial:			
Marshall black clay loam		67,920	
Miami stony loam	60,096		
gravelly loam	69,568		
sand	39,104		
sandy loam	42,240		
clay loam	1,089,216		
		1,300,224	
Volusia loam	173,440		
silt loam	78,464		
		251,904	
			1,620,048
Glacial lake and river terraces:			
Clyde clay		165,056	
Dunkirk gravel	2,880		
gravelly sandy loam	6,528		
gravelly loam	8,384		
fine sandy loam	42,048		
loam	2,880		
clay loam	20,352		
clay	18,880		
		101,952	
Muck and Peat		5,248	
			272,256
Total for State			2,652,224

OKLAHOMA.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Atlantic and Gulf Coastal Plains:	*Acres.*	*Acres.*	*Acres.*
Durant sand		4,288	
Durant fine sandy loam		25,728	
Harley sandy loam		8,832	
Houston loam	32,768		
black clay	75,392		
		108,160	
Orangeburg fine sandy loam		53,888	
			200,896
River flood plains:			
Meadow		3,904	
Miller fine sandy loam	11,136		
loam	37,184		
clay	1,280		
		49,600	
Teller fine sand		1,344	
Teller fine sandy loam		11,712	
Wabash fine sand	14.528		
fine sandy loam	9,792		
silt loam	11.968		
clay	6,016		
silt clay	4,992		
		47,296	
			113,856

Area of soils surveyed in the several States arranged in provinces and series—Continued.

OKLAHOMA—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Residual soils of the western prairie:	*Acres.*	*Acres.*	*Acres.*
Rough stony land		30,784	
Tishomingo gravelly sandy loam		29,696	
Vernon sand	11,776		
fine sand	44,928		
sandy loam	9.984		
fine sandy loam	162,048		
silt loam	131,072		
clay	9,216		
		369,024	
			429,504
Total for State			744,256

OREGON.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Northwestern intermountain region:	*Acres.*	*Acres.*	*Acres.*
Bridger gravelly loam	17.216		
loam	30,784		
		48,000	
Gallatin loam		29,760	
Meadow		12,352	
Rock outcrop		192	
Yakima loam		10.816	
			101,120
Pacific coast:			
Salem gravelly loam	13,120		
fine sandy loam	3,648		
silt loam	78,656		
clay	86,400		
		181,824	
			181,824
Total for State			282,944

PENNSYLVANIA.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Atlantic and Gulf Coastal Plains:	*Acres.*	*Acres.*	*Acres.*
Elkton silt loam		512	
Norfolk gravelly loam	17,350		
fine sand	12,160		
loam	3,648		
silt loam	7,942		
		41,100	
			41,612
River flood plains:			
Huntington fine sandy loam	4.992		
loam	5.056		
		10.048	
Meadow		50,204	
			60,252
Piedmont Plateau:			
Brandywine loam		24,000	
Cardiff slate loam		768	
Cecil stony loam	40.348		
clay loam	45.376		
clay	1,088		
		86,812	
Chester stony loam	20,864		
mica loam	10.640		
fine sandy loam	6,080		
loam	251,456		
		289,040	
Conowingo barrens		2.944	
Conowingo clay		4,160	
Lansdale silt loam		99.136	
Manor stony loam		38.956	
Manor loam		76,736	
Penn stony loam	58,760		
shale loam	100.032		
sandy loam	43.982		
loam	110.154		
silt loam	61.824		
		374,752	
Rough stony land		14.976	
			1,012,280

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

PENNSYLVANIA—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Appalachian Mountains and Plateau:	*Acres.*	*Acres.*	*Acres.*
Chemung stony loam		3,328	
Dekalb stony sandy loam	18,688		
stony loam	309.908		
shale loam	288,538		
gravelly loam	4,800		
sandy loam	11,220		
fine sandy loam	5,632		
silt loam	46,464		
loam	20,928		
clay	3,072		
		709,250	
Lickdale clay loam		16,016	
Morrison sand		576	
Morrison sandy loam		2,560	
Morrison fine sandy loam		1,600	
Porters stony loam	41,472		
clay	27.264		
		68,736	
Rough stony land and Steep broken land		96,192	
Upshur stony sandy loam	2.368		
stony loam	39,680		
loam	1,536		
		43,584	
			941,842
Limestone valleys and uplands:			
Conestoga loam		52,344	
Frankstown stony loam		2,048	
Hagerstown stony loam	35,072		
sandy loam	1.792		
loam	185,470		
silt loam	34.432		
clay loam	27,144		
clay	2,000		
		285,910	
			340,302
Total for State			2,396.288

RHODE ISLAND.

River flood plains:	*Acres.*	*Acres.*	*Acres.*
Meadow			1,920
Glacial and loessial:			
Gloucester stony loam		325,120	
Miami stony sandy loam	69,952		
stony loam	149.952		
silt loam	4.928		
		224,832	
			549,952
Glacial lake and river terraces:			
Dunesand and Coastal beach		2,176	
Merrimac coarse sand	26.304		
coarse sandy loam	82.816		
		109,120	
Swamp, Tidal swamp and marsh		31,232	
			142,528
Total for State			694,400

SOUTH CAROLINA.

Atlantic and Gulf Coastal Plains:	*Acres.*	*Acres.*	*Acres.*
Norfolk coarse sand	9,024		
sand	256,768		
fine sand	61,504		
sandy loam	353,472		
fine sandy loam	95,168		
silt loam	26.880		
		802,816	
Orangeburg coarse sandy loam	8,256		
sand	97.280		
sandy loam	64.512		
clay	6,784		
		176,832	

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

SOUTH CAROLINA—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Atlantic and Gulf Coastal Plains—Continued.	*Acres.*	*Acres.*	*Acres.*
Portsmouth sandy loam	334,064		
fine sandy loam	71,424		
		455.488	
Sandhill and Coastal beach		64.064	
Swamp, Tidal swamp and marsh		194,944	
			1,694,144
River flood plains:			
Congaree fine sandy loam	23,360		
loam	42,816		
clay	2,944		
		69,120	
Meadow		47,347	
			116,467
Piedmont Plateau:			
Cecil stony loam	2,637		
stony clay	1,280		
gravelly loam	23,744		
sand	67,878		
sandy loam	713,280		
fine sandy loam	160,128		
silt loam	159,808		
clay	891,379		
		2,020,134	
Iredell clay loam		56.832	
Rock outcrop		128	
			2,077,094
Appalachian Mountains and Plateau:			
Pilot loam		33,792	
Porters sand	15.238		
sandy loam	13,267		
fine sandy loam	24,128		
loam	33.664		
clay loam	26,432		
clay	26,509		
		139,238	
Rock outcrop		1,997	
			175,027
Total for State			4,062,732

SOUTH DAKOTA.

River flood plains:	*Acres.*	*Acres.*	*Acres.*
Meadow		11,392	
			11.392
Glacial and loessial:			
Marshall stony loam	8,256		
sandy loam	93,376		
loam	135.808		
black clay loam	43,456		
		280.896	
			280.896
Glacial lake and river terraces:			
Sioux sandy loam		28.864	
			28,864
Rocky Mountain valleys and plains:			
Orman clay		14,912	
Pierre clay loam		24,192	
Pierre clay		41,068	
Vale gravelly sandy loam		2,304	
Vale fine sandy loam		23,936	
Vale loam		3,520	
			109,952
Total for State			431,104

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

TENNESSEE.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Atlantic and Gulf Coastal Plains:	*Acres.*	*Acres.*	*Acres.*
Norfolk sandy loam		1,984	
			1,984
River flood plains:			
Huntington gravelly loam	14.464		
loam	5.824		
silt loam	36,928		
		57,216	
Meadow		17.216	
Wabash silt loam		38.850	
Waverly loam	64.448		
silt loam	43.968		
		108.416	
			221,698
Appalachian Mountains and Plateau:			
Clinch shale loam		26.752	
Dekalb stony loam	126,720		
shale loam	64.896		
sandy loam	163,392		
silt loam	16.512		
		371,520	
Grainger shale loam		20,288	
Holston loam		1,472	
Lickdale clay loam		17,024	
Rock outcrop and Rough stony land		28.992	
			466,048
Limestone valleys and uplands:			
Clarksville stony loam	655,380		
loam	80,448		
silt loam	362,434		
clay loam	27,460		
		1,125,722	
Conestoga clay		47,168	
Cumberland loam		53,824	
Davidson loam		20,352	
Decatur silt loam	960		
clay loam	6,592		
clay	15,040		
		22,592	
Fort Payne clay loam		9.536	
Guthrie silt loam		128	
Guthrie clay		5.800	
Hagerstown stony loam	110,464		
stony clay	9.792		
sandy loam	5.760		
loam	331,840		
clay	21,568		
		479.424	
Moccasin stony clay		3.840	
Newman stony loam		896	
Rough stony land		6.656	
			1,775,938
Glacial and loessial:			
Lexington silt loam		342,272	
Memphis silt loam		197,120	
Safford silt loam		28,544	
			567,936
Total for State			3,033,604

TEXAS.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Atlantic and Gulf Coastal Plains:	*Acres.*	*Acres.*	*Acres.*
Bastrop sandy loam	7.680		
fine sandy loam	32.320		
silt loam	6,060		
clay	12.352		
		58.432	
Caddo fine sandy loam		9,152	
Calcasieu fine sandy loam		23,040	
Crockett gravelly loam	3,008		
fine sandy loam	4,416		
loam	640		
clay loam	21,440		
		29,504	

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

TEXAS—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Atlantic and Gulf Coastal Plains—Continued.	*Acres.*	*Acres.*	*Acres.*
Houston gravelly clay	148,416		
loam	206,528		
black clay loam	54,272		
black clay	1,163,264		
clay	84,864		
		1,657,344	
Lake Charles fine sandy loam		38,784	
Lamar loam		5,696	
Laredo silt loam	16,768		
silty clay loam	33,216		
clay loam	704		
silty clay	448		
clay	3,904		
		55,040	
Lufkin gravelly loam	58,112		
sand	63,936		
fine sand	229,568		
sandy loam	362,944		
fine sandy loam	226,752		
loam	5,376		
clay	194,816		
		1,141,504	
Norfolk sand	76,272		
fine sand	650,944		
sandy loam	62,784		
fine sandy loam	578,092		
silt loam	24,128		
		1,392,220	
Orangeburg gravelly sandy loam	5,376		
sand	4,096		
fine sand	286,848		
sandy loam	15,104		
fine sandy loam	494,592		
clay	161,536		
		967,552	
Portsmouth sandy loam		15,488	
San Antonio clay loam		28,608	
Sandhill and Coastal beach		3,264	
Susquehanna gravel	58,560		
sandy loam	5,824		
fine sandy loam	512,000		
loam	3,392		
clay	52,544		
		632,320	
Tidal swamp and marsh		31,168	
Travis gravelly loam		25,728	
Webb gravelly sandy loam	53,760		
fine sand	3,136		
fine sandy loam	110,528		
loam	17,088		
		184,512	
Wilson fine sandy loam	4,288		
loam	98,880		
clay loam	71,872		
		175,040	
			6,474,396
River flood plains:			
Austin fine sandy loam		32,576	
Blanco loam		5,376	
Brennan fine sandy loam		11,584	
Cameron clay		27,072	
Franklin loam		1,280	
Lomalto clay		36,544	
Meadow		215,718	
Miller fine sand	15,296		
fine sandy loam	26,560		
silt loam	30,912		
clay	49,216		
		121,984	
Point Isabel clay		4,096	
Rio Grande silty clay		8,064	
Sanders loam		17,408	
Sanders silt loam		10,880	
Sharkey clay		183,296	
Swamp		320	
Wabash clay	239,552		
heavy clay	13,248		
		252,800	

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

TEXAS—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
River flood plains—Continued.	*Acres.*	*Acres.*	*Acres.*
Yazoo sandy loam		65,280	
Yazoo loam		25,280	
			1,019,558
Residual soils of the western prairie:			
Crawford stony clay	119,104		
loam	6,784		
silt clay	18,048		
clay	112,320		
		256,256	
Rock Outcrop and Rough stony land		29,312	
Vernon sand	56,448		
sandy loam	30,592		
fine sandy loam	5,248		
silt loam	59,392		
clay	22,592		
		174,272	
			459,840
Total for State			7,953,794

UTAH.

Great Basin:	*Acres.*	*Acres.*	*Acres.*
Bingham stony loam	62,222		
gravelly loam	132,112		
loam	12,100		
		206,434	
Elsinore sand		1,900	
Elsinore fine sandy loam		7,800	
Jordan sand	32,168		
fine sand	4,920		
fine sandy loam	48,620		
loam	95,700		
clay loam	161,280		
clay	6,528		
		349,216	
Malade fine sand	6,080		
sandy loam	3,264		
fine sandy loam	10,112		
loam	16,640		
		36,096	
Meadow		25,188	
Redfield fine sandy loam	44,200		
loam	14,100		
clay loam	3,800		
		62,100	
Riverwash		1,300	
Salt Lake sand	2,292		
sandy loam	51,308		
loam	19,968		
clay loam	89,166		
		162,734	
Weber fine sandy loam		107,904	
			960,672
Total for State			960,672

VERMONT.

River flood plains:	*Acres.*	*Acres.*	*Acres.*
Meadow			3,520
Glacial and loessial:			
Miami stony sandy loam		8,576	
Rock outcrop		4,288	
			12,864
Glacial lake and river terraces:			
Muck		384	
Swamp		1,280	
Vergennes stony loam	14,272		
gravelly loam	1,024		
fine sand	2,112		

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

VERMONT—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Glacial lake and river terraces—Continued.	*Acres.*	*Acres.*	*Acres.*
Vergennes sandy loam	1,984		
loam	2,304		
clay	102,080		
black clay	3,584		
		127,360	
			129,024
Total for State			145,408

VIRGINIA.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Atlantic and Gulf Coastal Plains:	*Acres.*	*Acres.*	*Acres.*
Coastal beach		12,736	
Chesterfield gravelly sandy loam		34,304	
Chesterfield sandy loam		95,680	
Elkton fine sandy loam		14,656	
Leonardtown loam		43,584	
Norfolk gravelly loam	1,344		
coarse sandy loam	4,288		
sand	11,200		
fine sand	20,864		
sandy loam	214,976		
fine sandy loam	230,272		
loam	23,872		
silt loam	5,952		
clay loam	1,856		
		514,624	
Portsmouth sand	2,048		
sandy loam	50,048		
fine sandy loam	29,760		
silt loam	55,488		
clay loam	2,176		
		139,520	
Swamp, Tidal swamp and marsh		67,072	
Wickham sand	4,416		
sandy loam	5,120		
loam	5,952		
clay loam	2,176		
		17,664	
			939,840
River flood plains:			
Congaree loam		9,984	
Huntington loam	2,560		
silt loam	576		
		3,136	
Meadow		142,208	
Swamp		2,432	
Toxaway fine sandy loam		2,176	
			159,936
Piedmont Plateau:			
Bradley sandy loam		59,072	
Cecil sand	59,558		
sandy loam	590,282		
fine sandy loam	26,432		
loam	108,992		
silt loam	4,928		
clay	331,312		
		1,121,504	
Chester mica loam	3,200		
loam	172,736		
		175,936	
Conowingo barrens		6,976	
clay		6,272	
Iredell clay loam		141,086	
Loudoun sandy loam		27,200	
Penn stony loam	1,280		
gravelly loam	512		
sandy loam	5,568		
loam	17,536		
clay	25,664		
		50,560	
Worsham sandy loam		8,520	
			1,597.126

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

VIRGINIA—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Appalachian Mountains and Plateau:	*Acres.*	*Acres.*	*Acres*
Dekalb stony loam	177,408		
shale loam	100,698		
fine sandy loam	7,552		
silt loam	25,792		
		311,450	
Holston silt loam		576	
Indian loam		384	
Paris loam		1,536	
Pilot gravelly loam		2,752	
Pilot loam		8,960	
Porters sand	115,136		
sandy loam	46,150		
black loam	77,006		
clay	63,312		
		301,604	
Rock outcrop and Rough stony land		94,961	
Upshur silt loam		2,624	
			724,850
Limestone valleys and uplands:			
Conestoga clay		16,960	
Cumberland gravelly loam	3,840		
loam	2,368		
clay loam	192		
		6,400	
Decatur clay loam		448	
Hagerstown stony loam	100,974		
sandy loam	57,414		
loam	98,568		
silt loam	20,160		
clay loam	1,792		
clay	45,130		
		324,038	
Murrill clay loam		15,720	
Radford loam		701	
			364,270
Total for State			3,786,022

WASHINGTON.

Glacial and loessial:	*Acres.*	*Acres.*	*Acres.*
Bellingham silt loam		13,056	
Custer loam		8,128	
Custer silt loam		8,960	
Lynden gravelly loam		16,640	
Lynden sandy loam		30,208	
Lynden fine sandy loam		5,696	
Lynden silt loam		16,256	
Miami stony sand	71,744		
stony loam	23,488		
stony sandy loam	25,792		
gravelly sand	33,600		
gravelly sandy loam	23,360		
sandy loam	184,320		
clay loam	2,240		
		364,544	
Rock outcrop		256	
Whatcom stony loam		28,608	
Whatcom silt loam		62,592	
			554,944
Glacial lake and river terraces:			
Clyde gravelly sandy loam	5,952		
sandy loam	1,792		
loam	1,216		
		8,960	
Muck and Peat		32,704	
Snohomish sand		21,504	
Snohomish fine sandy loam		9,728	
Snohomish silt loam		16,192	
Swamp, Tidal swamp and marsh		8,896	
			97,984
Northwestern intermountain region:			
Columbia silt loam		26,688	
Gallatin gravelly loam	10,048		
loam	3,392		
		13,440	

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

WASHINGTON—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Northwestern intermountain region—Continued.	*Acres.*	*Acres.*	*Acres.*
Meadow		15,060	
Riverwash		3,580	
Walla Walla silt loam		23,360	
Yakima stony loam	8,960		
fine sand	20,660		
fine sandy loam	149,580		
silt loam	64,896		
		244,096	
			326,224
Pacific coast:			
Coastal beach		2,624	
Puget fine sandy loam		18,816	
Puget silt loam		22,080	
Puget clay		33,984	
Tidal swamp and marsh		320	
			77,824
Total for State			1,056,976

WEST VIRGINIA.

River flood plains:	*Acres.*	*Acres.*	*Acres.*
Huntington fine sandy loam	2,176		
loam	32,704		
		34,880	
Meadow		11,968	
Tyler silt loam		3,008	
Wheeling gravelly loam	3,712		
sandy loam	768		
silt loam	2,816		
		7,296	
			57,152
Piedmont Plateau:			
Chester loam			4,160
Appalachian Mountains and Plateau:			
Dekalb stony loam	89,152		
shale loam	7,808		
sandy loam	1,920		
loam	60,608		
silt loam	27,136		
clay	40,768		
		227,392	
Meigs clay loam		281,280	
Porters clay		192	
Rough stony land and Steep broken land		403,456	
Upshur clay		16,064	
			928,384
Limestone valleys and uplands:			
Brooke clay loam		38,464	
Hagerstown sandy loam	1,216		
clay	4,224		
		5,440	
			43,904
Total for State			1,033,600

WISCONSIN.

River flood plains:	*Acres.*	*Acres.*	*Acres.*
Meadow		36,544	
Wabash loam		29,632	
			66,176
Glacial and loessial:			
Marshall gravelly loam	24,064		
sand	31,040		
loam	3,200		
silt loam	102,208		
clay loam	70,528		
black clay loam	1,856		
		232,896	
Miami stony sand	17,536		
stony loam	5,632		
gravel	15 104		

Area of soils surveyed in the several States, arranged in provinces and series—Continued.

WISCONSIN—Continued.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Glacial and loessial—Continued.	*Acres.*	*Acres.*	*Acres.*
Miami sand	179,520		
fine sand	16,256		
sandy loam	198,784		
loam	84,736		
silt loam	282,624		
clay loam	31,040		
		831,232	
Portage stony sandy loam		11,392	
Portage sandy loam		9,792	
Portage silt loam		22,656	
Rock outcrop		2,240	
			1,110,208
Glacial lake and river terraces:			
Clyde fine sandy loam	1,216		
clay loam	12,224		
		13,440	
Dunesand		512	
Dunkirk fine sandy loam		5,568	
Muck and Peat		208,576	
Sioux sand	19,520		
sandy loam	59,840		
silt loam	6,656		
		86,016	
Superior sandy loam	14,208		
clay	154,688		
		168,896	
			483,008
Total for State			1,659,392

WYOMING.

Province and soil name.	Area of types in series.	Total for series and types.	Total for province and State.
Great Basin:	*Acres.*	*Acres.*	*Acres.*
Redfield fine sandy loam		42,624	
Gypsum		2,304	
			44,928
Rocky Mountain valleys and plains:			
Billings clay		16,064	
Laramie gravelly loam	19,200		
sandy loam	86,272		
		105,472	
Laurel sandy loam		29,440	
Riverwash		1,792	
			152,768
Total for State			197,696

CHANGED SOIL NAMES.

The following list gives the soil names in published reports that as a result of subsequent correlation have been dropped. In the first column is given the original name; in the second, the name at present used.

Name as published.	Changed to—
Afton fine sandy loam	Miami fine sand.
Alamance silt loam	Cecil silt loam.
Allegan black clay	Clyde loam.
Allegan clay	Miami clay loam.
Allegan fine sandy loam	Miami fine sand.
Allegan gravelly loam	Miami gravelly sandy loam; Miami gravelly sand
Allegan sand	Miami sand.
Allegan sandy loam	Miami sandy loam.
Allegan stony loam	Miami stony loam.
Almyra silt loam	Crowley silt loam.
Alton stony loam	Miami stony sandy loam.
Arkansas fine sandy loam	Wabash fine sandy loam.
Arkansas loam	Laurel loam.
Arroyo Seco sandy loam	Maricopa gravelly loam.
Austin clay	Houston clay.
Ayden fine sandy loam	Norfolk fine sandy loam.
Benton loam	Houston clay.
Billings sandy loam	Billings fine sandy loam.
Boise sandy loam	Boise silt loam.
Caldwell loam	Gallatin silt loam.
Caldwell sandy loam	Gallatin fine sandy loam.
Cecil mica loam	Chester mica loam.
Chicopee gravel loam	Norfolk gravelly loam.
Clarksville clay	Waverly clay.
Clarksville loam	Wabash silt loam.
Colorado adobe	Colorado loam adobe; Laurel loam adobe.
Colton stony clay	Crawford stony clay.
Connecticut Meadow	Meadow.
Connecticut Swamp	Swamp.
Dauphin sandy loam	Dekalb sandy loam.
Davie clay loam	Cecil loam; Cecil fine sandy loam.
Deer Flat sandy loam	Deer Flat fine sandy loam.
Dekalb clay loam	Lickdale clay loam.
Delavan silt loam	Sioux silt loam.
Donegal gravelly loam	Norfolk gravelly loam.
Durham sandy loam	Cecil sand.
Edgemont stony loam	Dekalb stony loam.
Edgerton silt loam	Miami silt loam.
Elkhorn silt loam	Wabash silt loam.
Elkton clay	Portsmouth silt loam in Mason County, Ky.; and in all Maryland areas heretofore surveyed, and to Elkton silt loam in Delaware and New Jersey areas.
Elmira fine sandy loam	Wabash loam.
Elmira shale loam	Dunkirk shale loam.
Elmira silt loam	Dunkirk silt loam.
Elsinboro fine sand	Norfolk fine sand.
Elsinore sandy loam	Elsinore fine sandy loam.
Fairview sandy loam	Marshall sandy loam.
Fancher sandy loam	Stockton fine sandy loam; Hanford sandy loam.
Fargo gravelly loam	Marshall gravelly loam.
Fargo loam	Marshall loam.
Fort Payne clay	Conestoga clay.
Fort Payne loam	Hagerstown loam.
Fort Payne stony loam	Clarksville stony loam.
Fresno gravel	Hanford gravel.
Fresno gravelly sand	Maricopa sand.
Fresno red sand	San Joaquin sand.
Fullerton sandy adobe	Placentia loam adobe; Placentia sandy adobe.
Galveston coarse sand, sand, and fine sand	Coastal beach.
Galveston sandy loam and clay	Tidal swamp and marsh.

Name as published.	Changed to—
Garner stony loam	Susquehanna gravelly loam.
Glendale loess	Glendale clay loam.
Glenwood loam	Bingham loam.
Goldsboro compact sandy loam	Portsmouth sandy loam.
Hagerstown shale loam	Dekalb shale loam; Volusia silt loam.
Hagerstown silt loam	Clarksville silt loam.
Hanover sand	Miami sandy loam.
Hartford sandy loam	Merrimac sandy loam.
Hempfield stony loam	Cecil stony loam.
Hempstead gravelly loam	Hempstead loam.
Herndon stony loam	Porters stony loam.
Hondo meadows	Meadow.
Houston silt loam	Houston loam.
Imperial fine sandy loam	Gila loam.
Imperial gravelly loam	Indio gravelly loam.
Imperial loam	Imperial clay loam; Gila clay loam.
Imperial silt loam	Gila silt loam.
Janesville loam	Sioux silt loam.
Janesville silt loam	Marshall silt loam.
Jordan meadow	Meadow.
Jordan sandy loam	Jordan fine sandy loam; Jordan loam.
Kalamazoo gravelly loam	Clyde gravelly sand.
Kaskaskia loam	Wabash silt loam.
Leonardtown gravelly loam	Leonardtown loam.
Lincoln sandy loam	Laurel fine sandy loam.
Los Angeles sandy loam	Placentia loam.
Lufkin clay loam	Lufkin clay.
Mackinaw gravel	Miami gravel.
Maricopa sandy adobe	Colorado loam adobe; Placentia sandy adobe.
Maricopa stony loam	Bingham stony loam.
McLean silt loam	Marshall loam.
Miami black clay loam	Marshall black clay loam.
Miller heavy clay	Miller clay.
Monroe fine sandy loam	Miller fine sandy loam.
Murrill sandy loam	Hagerstown sandy loam.
Murrill stony loam	Hagerstown stony loam.
Norfolk sandy soil	Norfolk sandy loam.
Oakland sandy loam	Miami fine sandy loam.
Orangeburg silt loam	Miller silt loam.
Oswego loam	Oswego silt loam.
Pecos gypsum	Gypsum.
Pecos sand	Gila fine sandy loam; Gila fine sand.
Placentia coarse sandy loam	Placentia sandy loam.
Plainwell stony loam	Miami stony sand.
Pocoson	Swamp.
Porters red clay	Porters clay.
Portsmouth clay	Portsmouth loam.
Quinton sandy loam	Norfolk sandy loam.
Redfield sandy loam	Redfield fine sandy loam.
Rio Grande loam	Laurel clay loam.
Rio Grande sandy loam	Laurel sandy loam.
Roswell sandy loam	Roswell fine sandy loam.
Salem loam	Salem silt loam.
Salem sandy loam	Salem fine sandy loam.
Salinas shale loam	Oxnard gravelly loam.
Salt River adobe	Gila clay.
Salt River gravel	Rough stony land.
San Gabriel gravelly loam	Maricopa gravelly loam.
San Gabriel gravelly sand	Maricopa gravelly sand.
San Gabriel sandy loam	Maricopa sandy loam.
San Jacinto clay	Houston black clay.
San Joaquin black adobe	Oxnard clay loam adobe; Billings clay; Stockton clay loam adobe.
San Joaquin red adobe	San Joaquin clay loam adobe; San Joaquin sandy adobe.
Santiago sandy loam	Santiago fine sandy loam.
Santiago silt loam	Hanford clay loam; Gila loam; Gila silt loam; Gila clay loam; Hanford silt loam; Laurel loam.
Savanna	Swamp.
Sedgwick clay loam	Marshall silt loam; Crawford silt loam.
Sedgwick gravelly loam	Crawford gravelly loam.
Sedgwick loam	Colorado loam.
Sedgwick sandy loam	Colorado sandy loam.
Selma clay	Norfolk clay.
Selma heavy silt loam	Portsmouth sandy loam; Portsmouth fine sandy loam.
Selma silt loam	Norfolk sandy loam.
Shelby clay	Shelby loam.
Sierra adobe	Sierra sandy adobe; Placentia clay loam adobe.
Sierra loam	Sierra loam adobe.
Snake River sand	Yakima fine sand.
Soledad gravelly sand	Maricopa gravelly sand.
Sturgis fine sandy loam	Norfolk fine sandy loam.
Sunnyside sand	Yakima fine sand.
Susquehanna gravel	Norfolk gravel.

Name as published.	Changed to—
Tazewell silt loam	Miami silt loam.
Triassic stony loam	Penn stony loam.
Vernon fine sand	Miller fine sand.
Vernon loam	Vernon silt loam.
Volusia sandy loam	Volusia loam.
Waldo loam	Wabash silt loam.
Walla Walla loam	Walla Walla silt loam.
Warwick sandy loam	Norfolk coarse sandy loam.
Westphalia sand	Norfolk fine sand.
Willis sand	Norfolk fine sandy loam.
Windsor sand	Norfolk coarse sand.
Winnebago sandy loam	Marshall sandy loam.
Yakima gravelly loam	Gallatin gravelly loam.
Yakima sandy loam	Yakima silt loam; Yakima loam; Yakima fine sandy loam.
Yakima stony clay	Rough stony land.
Yazoo clay	Waverly clay; Crawford clay; Wabash clay.
Yazoo heavy clay	Wabash heavy clay.
Yazoo silt loam	Wabash silt loam.

ALPHABETICAL INDEX TO SOIL SERIES AND MISCELLANEOUS TYPES.

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Issued March 6, 1909.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF SOILS—BULLETIN NO. 56.

MILTON WHITNEY, *Chief.*

THE RÔLE OF OXIDATION IN SOIL FERTILITY.

BY

OSWALD SCHREINER AND HOWARD S. REED.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1909.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., September 22, 1908.

Sir: I have the honor to transmit herewith the manuscript of a technical paper entitled "The Rôle of Oxidation in Soil Fertility," by Oswald Schreiner and Howard S. Reed, of this Bureau. This article embodies the results of work carried out in the Bureau and contains important information on some little-understood factors involved in the study of soil fertility. The facts here presented emphasize the beneficial effects of tillage and other practices conducive to thorough aeration of the soil, although the present study has been mainly along the line of oxidation processes in the soil, induced by the roots of growing crops.

The oxidation by roots of crops growing in the soil is an agent in soil improvement which has until recently been almost overlooked. The mild but effective oxidation produced in this way is shown to have a very appreciable effect in aiding the decomposition of organic matter in the soil. The importance of the organic constituents of the soil, as shown by our recent investigations, makes these results especially interesting, and the material throws additional light upon the question of soil fertility. In accordance with your suggestion the manuscript has been gone over carefully with Assistant Secretary Hays, who authorizes me to state that he concurs in my recommendation for its publication. This will form No. 56 in the series of bulletins of the Bureau of Soils.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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THE RÔLE OF OXIDATION IN SOIL FERTILITY.

INTRODUCTION.

Oxidation is one of the most important processes in the soil, and while well recognized in the practical tillage of soils, the process itself and the forces which tend to promote oxidation have not been well understood nor much studied. Oxidation in soils may be produced by several different agencies, among which are the following:

Changes brought about by purely chemical processes in which the oxygen in the air attacks the soil compounds, producing higher oxidized forms. In this class should be included the interaction between chemical individuals of the same kind, resulting in the oxidation of one at the expense of the other—the process technically known as auto-oxidation. To this also should be added the influence of agents in the nature of fertilizers which have oxidizing properties, such as manganese or ferric compounds, nitrates, etc., as well as those which by changing the reaction of the soil increase the direct oxidation by atmospheric oxygen and oxidizing agents, which usually takes place more readily under alkaline conditions. The nascent production of nitric acid in the soil may also be a factor in the direct chemical oxidation of soil compounds.

Bacteria and the oxidizing enzymes which they produce are known to play an important part in oxygen fixation in soils, especially those relatively rich in organic matter, although the chemistry involved has not been extensively investigated and is but little understood.

The plant roots and the oxidizing enzymes produced by them in the soil constitute other agencies of oxidation which until recently were almost overlooked and even unknown. The mild but effective oxidation produced in this way by the roots of the growing crops and enzymes in the soil has a very appreciable effect in altering some of the soil constituents, and thus influencing soil fertility, through the action of added fertilizers and systems of rotation on this oxidizing power.

The present paper[a] embodies a series of studies upon the oxidizing powers of plant roots grown in aqueous extracts of soils and in solutions of various compounds. The results, it is believed, throw some light on the action of plants upon the soil and indicate how soil conditions affect certain functions of the plant. Recent work in soil fertility has shown that in many cases the constituents of soil and of fertilizers, in addition to furnishing plant nutrients, perform a variety of other functions. These studies show the influence of constituents of soil and of fertilizers upon the important function of oxidation.

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[a] The authors wish to acknowledge the valuable assistance rendered by Mr. J. J. Skinner, of this Bureau, in carrying out many of the experiments reported in this bulletin.

THE RÔLE OF OXIDATION IN PROMOTING CHEMICAL CHANGES IN SOILS.

The experiments which are presented in this paper show that plant roots are able to carry on active extra-cellular oxidation, chiefly by means of the enzymes which they secrete. From the standpoint of root excretions the study is of interest because it has often been supposed that the roots of growing plants excrete organic and inorganic acids which aid in the solution of soil minerals. The idea undoubtedly owes its prevalence largely to the experiments of Liebig[a] and of Sachs,[b] which demonstrated the corrosion of polished marble plates by growing plants. The more recent investigations upon the subject made by Czapek,[c] Kossowitch,[d] and Kunze[e] have shown, however, that very little acid is excreted by the roots of the higher plants, and that the results of the earlier workers were mainly due to the action of carbon dioxide.[f]

Although the solvent action of the roots upon soil constituents as a result of the acids secreted is slight, if any, this oxidizing power gives them an important action upon the soil. Whether they have the power to oxidize the inorganic constituents of the soil remains to be determined; but it has been shown that they are able to oxidize organic substances, such as the chromogens employed in these experiments, at a fairly rapid rate. If these substances are oxidized it is only logical to conclude that the organic substances occurring in the soils are also oxidized by the action of plant roots.

In the light of this oxidizing power, certain relations of plants to organic materials in the soil become of the highest interest. The toxicity of certain organic compounds has been shown by the writers[g] to be materially decreased by the addition of sodium nitrate or calcium carbonate to the cultures in which plants were grown. It was found that the toxicity of a vanillin solution was somewhat decreased when calcium carbonate was allowed to remain in contact with it for ten days; but a similar action was not observed when sodium nitrate was used in the same way. Also, when a preliminary set of plants was grown in solutions of certain compounds the activities of the plant roots were able to decrease the toxicity to a certain extent, provided the original concentration of the solution was not fatal to the plants. The preliminary set of plants undoubtedly absorbed and removed some of the toxic material from the solution, but the greatly diminished toxicity of the solutions as well as the formation of dyestuffs indicated that other changes had taken place. The greatest decrease in toxicity was obtained when sodium nitrate or calcium carbonate was added to the toxic solution at the time of installing the preliminary set of plants. In other words, the activity of the plant roots working in the presence of the inorganic salts was able to accomplish far more in the amelioration of toxic conditions than either agent taken singly could do. Upon further investigation it was found that the toxic compounds were entirely absent after the plants had grown in solutions to which the sodium nitrate and calcium carbonate had been added, while fairly large amounts were present in corresponding solutions in which plants had been grown a similar length of time, but without the addition of the inorganic salts.

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[a] Ann. Chem. Pharm., **105**, 139 (1858).

[b] Bot. Ztg., **18**, 117 (1860).

[c] Jahrb. wiss. Bot., **29**, 321 (1896).

[d] Ann. Sci. Agron. [2], 8 (1), 220 (1903).

[e] Jahrb. wiss. Bot., **42**, 357 (1906).

[f] In this connection also see the recent work of Stoklasa and Ernest, Jahrb. wiss. Bot., **46**, 55 (1908).

[g] Jour. Am. Chem. Soc., **30**, 85 (1908); Bul. 40, Bureau of Soils, U. S. Dept. Agr., 1907.

In the light of the data presented in this paper showing the power of sodium nitrate and calcium carbonate to increase the oxidizing power of plants, the ameliorating influence of these salts as shown in the previous work is made more intelligible. It would seem from these data that the amelioration observed is largely to be referred to the increased oxidizing power of the plants caused by the addition of the inorganic salts, especially since it has been shown[a] that the highly oxidized form of certain toxic compounds are less likely to be injurious than the less oxidized forms.

The beneficial effects of processes which involve oxidation have been well shown in the publication cited by the effects of neurine, choline, and betaine. Neurine, which is very toxic to wheat plants, contains the ethylene group Choline, which is less injurious than neurine, contains the ethyl instead of the ethylene group and has one carbon atom oxidized to the primary alcohol stage. Betaine, which is nontoxic, shows still more oxidation by having the alcohol group oxidized to carboxyl, with subsequent splitting off of water.

Another example of the beneficial effect of oxidation may be cited from the publications already mentioned. It was shown that a tyrosine solution lost its injurious properties upon long standing with exposure to the air, the solution becoming dark colored by oxidation. The changes wrought seemed to be the same as those produced by the action of tyrosinase, which oxidizes tyrosine to homogentisic acid and then to several dark-colored compounds. When plants were grown in this oxidized solution it was found that the injurious properties of the tyrosine had not only disappeared, but that the solution was actually beneficial to plant growth.

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[a] Schreiner and Reed, Bot. Gaz., 45, 73 (1908); Bul. 47, Bureau of Soils, U. S. Dept. Agr., 1907.

These results are believed to have importance in explaining the value and action of the so-called green manure used in agricultural practice. When green manures are first applied to the soil, they may exert a slightly injurious effect, but after time enough has elapsed for the oxidation and decomposition of the vegetable matter the crop shows a beneficial effect resulting from the action of these products of oxidation and decomposition.

While it would be presumptuous to assume that decrease in toxic action always accompanies the introduction of oxygen into organic compounds, it is undoubtedly true that in a number of cases the more highly oxygenated compounds are less toxic than those containing less oxygen.

This oxidation of organic compounds is of additional interest in the light of recent investigations, which show that the cause of unproductivity in certain soils is due to the presence of harmful organic compounds.[a] The productivity of such soils may be improved by the removal of these harmful compounds. The beneficial effects of oxidation in such soils may be inferred from the results of thorough tillage, involving subdrainage and cultivation, since these operations promote aeration of the soil with subsequent increase in growth of roots and microorganisms. Under such conditions experience has shown that the organic substances in the soil are most completely converted into substances commonly known as humus. It is certain that the oxidizing activities of the soil and plant play a significant part in this important process.

From our present knowledge of the conditions that are necessary for the maintenance of fertility in agricultural soils it appears that the process of oxidation plays an important part in maintaining productivity. Part of the oxidation in the soil is undoubtedly accomplished by the activity of microorganisms, but the growing plant roots are also a factor. It must be left to future investigations to delineate the exact course of changes which the oxidation produces. Enough evidence is at hand, however, to demonstrate that maintenance of the most favorable soil conditions requires the oxidation of the organic soil constituents to a comparatively high stage of oxidation. The beneficial effects of oxidation are well illustrated by the case of the organic bodies, neurine, choline, and betaine, and by that of tyrosine. The same relations hold for inorganic bodies, as illustrated by the fact that elements like nitrogen, phosphorus, and sulphur are suitable for nutrients only when present in the form of nitrates, phosphates, and sulphates; the nitrites, sulphites, and phosphites being toxic. In this connection it is extremely interesting to note the conditions under which animal toxins have been found to arise and in turn become nontoxic. Vaughan and Novy state:[a] "It would seem, as Brieger has already pointed out, that a certain quantity of oxygen is necessary to the formation of poisonous bases. Free supply of oxygen, on the other hand, invariably yields nontoxic ptomains."

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[a] Jour Am. Chem. Soc., **30**, 1295, 1599 (1908); Buls. 36, 40, 53, Bureau of Soils, U. S. Dept. Agr.

PREVIOUS WORK.

The existence of an oxidation process in soils has long been known. Without apparently understanding the precise cause of this phenomenon, Liebig pointed out its importance for productive soils, and, according to the same author, the phenomenon had been earlier investigated by Ingenhouss and De Saussure.

Deherain and Demoussy,[b] in studying the process of oxidation of the organic matter in several soils, found that oxygen was always taken up and carbon dioxide set free. The oxidation was attributed by the authors to the activity of micro-organisms and to regular chemical action, with rather strong indications that the chemical action was due to enzymes.

Wollny[c] studied the rate of oxidation by estimating the amount of carbon dioxide produced by 100 grams of soil in a given time at a constant temperature. The oxidation was by him attributed mainly to the activity of micro-organisms. His results confirm those of Deherain and Demoussy and in addition showed that the presence of antiseptics, like mercuric bichloride, phenol, thymol, etc., decreased, if not inhibited, the process of oxidation. The processes of oxidation resulting in nitrification and the production of carbon dioxide were favored by slightly alkaline conditions, such as those secured by the addition of lime. The oxidation processes were retarded by the addition of chlorides and sulphates to the soil, but were favored by the addition of phosphates and nitrates.

Russell[d] has used an improved method for studying the problems attacked by the preceding investigators. He has shown that, generally speaking, the rate of oxidation is higher in fertile soils than in infertile soils, in the surface soil than in the subsoil. The rate of oxidation was found to increase with the temperature, the amount of water (up to a certain point), and the amount of calcium carbonate. The observed disappearance of oxygen and formation of carbon dioxide was attributed to the action of micro-organisms.

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[a] Cellular Toxins, p. 248, Philadelphia, 1902.

[b] Ann. agron., 22, 305 (1896).

[c] Die Zersetzung der organischen Stoffe und die Humusbildungen, Heidelberg, 1897.

[d] Jour. Agr. Sci., 1, 261 (1905).

In a subsequent piece of work, Darbishire and Russell[a] have studied the effects of partial sterilization upon the oxidation by the soil. They found that heating the soil to 100° C., or treatment with volatile antiseptics, which were subsequently removed, led to a marked increase in the amount of oxygen absorbed. The increased oxidation was attributed to the removal of organisms which formerly competed with the oxidizing organisms without on their own part being beneficial to oxidation.

If the increased oxidation and increased plant growth are primarily the result of the removal of certain microorganisms it is still difficult to see why, in their experiments of partial sterilization with copper sulphate and mercuric chloride, decreased oxidation was observed in some soils and irregular increases in others. It is just as probable that the favorable influence on oxidation and plant growth are due to the destruction of toxic organic compounds which previously retarded both plant growth and oxidation, whether by microorganisms, enzymes, or other vital agencies. This assumption is certainly in harmony with the results obtained by Nobbe and Richter[b] by treating the soil with ether, carbon bisulphide, chloroform, and benzene, and they themselves reject the idea of amelioration through the action of these compounds on microorganisms.

In connection with observations that oxidation in the soil is due to the activities of microorganisms, it is important to note that recent bacteriological investigations[c] have demonstrated that certain soil bacteria under anaerobic conditions will oxidize hydrogen. Interesting in this connection is also the work of Potter[d] in showing a slow oxidation of amorphous carbon by bacteria. Chodat[e] has adduced evidence that the important action of nitrifying bacteria is largely, if not entirely, a process of oxidation by means of the nitroxidase which they produce.

On the other hand, there have been put forth some facts which indicate that part of the oxidation may be brought about by enzymes.

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[a] Jour. Agr. Sci., **2**, 305 (1907).

[b] Landw. Vers-Stat., **60**, 433 (1904).

[c] Kaserer, Centralbl. Bakt. (2), **16**, 681, 769 (1906); Nabokich and Lebedeff, ibid. (2), **17**, 350 (1906); Niklewski, ibid. (2), **20**, 469 (1908).

[d] Proc. Roy. Soc., B, **80**, 239 (1908).

[e] Bul. Herb. Boissier (2), **6**, 512 (1906).

Woods[a] found evidence that oxidase and peroxidase were present in the soil. Cameron and Bell[b] reported that many soils when shaken with an alcoholic solution of guaiac gave the blue color characteristic of oxidases.

Recent studies by König[c] furnish evidence of a catalytic power of soils due to the presence of an enzyme. He found that the different soils tested had the ability to liberate oxygen from hydrogen peroxide in addition to giving a blue coloration to a solution of paraphenylene diamine. This action was almost, if not entirely, destroyed by treating the soil with hydrocyanic acid, chloroform, and by dry or moist heat. The soils which were richest in humus had the greatest power to decompose hydrogen peroxide. König assumes that there is some catalytic action due to the colloidal substances present in the soil, since even the treatment with heat and hydrocyanic acid did not entirely inhibit the decomposition of hydrogen peroxide. In support of this assumption, König showed that the sesquioxides of manganese, iron, and chromium are able to effect a material production of oxygen from hydrogen peroxide, but other substances like apatite, feldspar, oxides of zinc, cadmium, and calcium, however, did not attack hydrogen peroxide.

The literature dealing with the oxidizing power of plant juices is already voluminous. Within recent years our knowledge of processes going on within the plant has been greatly extended by the studies which have been made upon oxidizing enzymes. Since several comprehensive and instructive summaries of work on this subject have appeared, among which may be mentioned those of Bach and of Czapek's Biochemie, it is unnecessary in the present paper to review in detail what has been done in this rapidly developing field.

The study of the oxidizing enzymes which are given off by the roots of plants—i. e., extra-cellular oxidation—has received less attention, and it is to this particular field that the present study belongs.

Molisch[d] appears to have been the first to demonstrate the oxidizing power of root secretions and to show their enzymatic nature. He found that the root secretion was capable of oxidizing various organic substances, such as guaiacol, pyrogallol, gallic acid. His work showed that there was considerable active secretion on the surface of growing roots and that this secretion had definite powers to effect changes in organic substances.

Czapek[e], in making a general study of root secretions, followed some of the investigations made previously by Molisch. From experiments upon the action of seedling roots upon starch paste and sugar solutions, he regarded it probable that the growing roots produce only diastase or inverting ferments, although exact proof could not be offered. He believed, however, that the experiments of Molisch failed to prove the production of oxidizing enzymes by roots.

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[a] Centralbl. für Bakt. (2) **5**, 745 (1899); Bul. 18, Bureau of Plant Industry, U. S. Dept. of Agr., 1902.

[b] Bul. 30, Bureau of Soils, U. S. Dept. of Agr., 1905.

[c] Landw. Vers.-Stat., **63**, 471 (1906); **66**, 401 (1907).

[d] Sitzungsber. Akad. wiss. Wien. Math. nat. Kl., **96**, 84 (1888).

[e] Jahrb. wiss. Bot., **29**, 321 (1896).

Subsequent work by Czapek[a] establishes the existence of an intracellular oxidase in the roots of Vicia seedlings. It was found that "a short time after the beginning of geotropic induction there appears a retardation of the normal destruction of tyrosine, to be recognized by an accumulation of homogentisic acid." The cause of this retardation is attributed to the development of a specific antioxidase which inhibits the normal activity of the oxidase of the root tip. In normally growing roots the action of the oxidase appears to play a very definite rôle in the intra-cellular activities.

The ideas of the oxidizing powers of roots set forth by Molisch are well corroborated by the investigations of Raciborski[b] upon the oxidizing powers of plant tissues.

In his work reagents were used which were so nearly nontoxic that they could be added to solutions in which plants were grown. In some experiments the reagents were added to water cultures containing the growing plants; in others, strips of filter paper which had been saturated with the reagent were applied to the surface of growing roots. The substances used for showing the oxidizing power of growing roots were alpha-naphthylamine, benzidine, phenolphthalin, ferrous ammonium sulphate, Barbadoes aloes, guaiac, phlóridzin, pyrogallol, leucomethylene blue, etc.

The extracellular oxidation by the roots of the phanerogams studied was found to be strongly localized and limited to the absorbing surface of the root. The most intensive oxidation occurs in the region covered by the root hairs. After the death of the root hairs, as the root grows older, the oxidation becomes weaker (as shown by the less intense coloration) and vanishes in basipetal order. The short growing zone of the root between the root cap and the region of root hairs shows very little, if any, oxidation. The cells of the root cap behaved differently in different plants. In some there was a very weak oxidizing power, insignificant in comparison with that of the absorbing region of the root; in other plants the root cap showed no power to oxidize. This observation is the more interesting because Pfeffer[c] regarded the experiments of Molisch to lack proof that the guaiac-bluing power was due to living cells and not to the dead or dying cells of the root cap.

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[a] Jahrb. wiss. Bot., **43**, 145, 361 (1906). For a concise summary and bibliography of the articles describing this work, see Czapek, Ann. of Bot., **19**, 75 (1905).

[b] Bul. Acad. Sci. Cracovie, 1905, pp. 338, 668, 693.

[c] Abhandl. kön. säch. Ges. Wiss., Leipzig, Math. phys. Kl., **15**, 375 (189).

The oxidation which occurred in naphthylamine and benzidine solutions first appeared on the outer surfaces of the walls of the root hairs and epidermal cells, later in the wall itself, and finally in the outer layer of the ectoplasm. When roots were left for a long time in a solution of these chromogens, the entire protoplasm of the epidermal cells and root hairs gradually assumed the dark color of the oxidized chromogen, although it was not determined whether this color was due to the diffusion inward of the dye formed at the surface or to an actual intracellular oxidation.

MATERIAL AND METHODS.

The experiments described in succeeding pages consisted in studying the oxidizing power of wheat plants grown under various conditions in connection with soil-fertility investigations. It was necessary to grow the wheat plants used for experimentation in solutions, since in such cultures it is possible to observe the oxidation without disturbing the roots. For the study of soil conditions an aqueous extract was made by stirring 1 part soil with 5 parts distilled water for three minutes and filtering after thirty minutes through a Pasteur-Chamberland filter tube. It has been found that soil extracts prepared in this manner possess a plant-producing power similar to that of the soil from which they were made. In other words, fertile soils yield extracts which promote good plant growth, and infertile soils give extracts producing poor plant growth. The effect of fertilizers was studied by adding pure salts to the soil extract. In other cases where the action of certain salts was being studied, the plants were grown in dilute solutions of those salts.

The water used in making solutions and soil extract was the ordinary laboratory distilled water treated with carbon black. The water was distilled from a copper boiler, condensed in a block tin worm and collected in a tin-lined copper tank. This method of distillation gives very good water for ordinary chemical work, but does not free it from traces of volatile organic compounds which may exert a harmful action, as was described by Livingston[a] and the writers.[b] It has been found that these deleterious substances may be effectually removed by treating the distilled water with some finely divided solid which possesses a strong absorbing power, such as ferric hydrate, or carbon black. The procedure usually followed was to shake up a small quantity of the carbon black in the water and allow it to stand for thirty to sixty minutes. At the expiration of that time the water was filtered through ordinary filter paper and was ready for use. This treatment has been found to be as efficient in producing physiologically pure water as redistillation with strong oxidizing agents like acid potassium bichromate or alkaline potassium permanganate.

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[a] Bul. 36, Bureau of Soils, U. S. Dept. Agr., 1907.

[b] Bul. 40, Bureau of Soils, U. S. Dept. Agr., 1907.

The varieties of wheat used in the experiments were " Chul " and " Harvest Queen." The seeds were germinated on floating perforated plates, according to the method described by Livingston,[a] and in Bulletin 40 of this Bureau. The seedlings were transferred from the perforated germinating plates to the cultures just as the first true leaf was beginning to emerge from its sheath.

The plants were held in notches cut in the edge of a cork, as described by Livingston. In this way the seeds in which enzymes were acting upon reserve food materials were kept out of the solutions and the enzyme effects observed were ascribable to those from the roots.

Salt-mouth bottles, having a capacity of 250 c. c., were used as culture jars and 10 wheat plants were grown in each jar. In each test two cultures containing 20 wheat plants were usually employed, and comparison was made with an equal number of plants growing in pure distilled water under the same conditions. All experiments were conducted in a greenhouse. During the season of the year in which conditions were most favorable for growth, each experiment was continued for eight to twelve days before studying the oxidizing action of the plants, but during the cloudy winter weather the time was sometimes extended to fourteen or sixteen days.

In addition to determining the oxidizing power of the plants subjected to various treatments, their growth was estimated by recording the green weight and transpiration of each culture.[b]

SUBSTANCES CAPABLE OF SHOWING THE OXIDIZING POWER OF ROOTS.

Two classes of substances have been found useful in showing the oxidizing power of plant roots in solution cultures. The first class comprises certain soluble chromogens which yield, upon oxidation by the plant roots, insoluble colored compounds mainly deposited upon the surface of the roots. The oxidation is usually rapid enough to produce marked results before the surface extension of the roots disturbs the zonal distribution of the colors. The second class of chromogens consists of certain substances which give soluble coloring matters as the result of the oxidizing action of the roots. The oxidizing action may be shown by the change from a colorless to a colored compound or by a change from one color to another and distinctly different color.

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[a] Livingston, Plant World, **9**, 13 (1906).

[b] For a discussion of the value of these criteria the reader is referred to Livingston, Bot. Gaz., **40**, 178 (1905); Jensen, Bot. Gaz., **43**, 11 (1907); and Bul. 47, Bureau of Soils, U. S. Dept. Agr. 1907.

Compounds belonging to the first class which have been used in this work are alpha-naphthylamine, benzidine, vanillin, vanillic acid, and esculin.

Alpha-naphthylamine is only slightly soluble in water, but constitutes a good reagent for use in plant cultures, because its colorless solution is nontoxic, or nearly so, to plants. When oxidized by the roots of plants, or by reagents such as ferric chloride or silver nitrate, alpha-naphthylamine is converted into the insoluble, lavender-purple oxynaphthylamine. When the oxidation is performed by the growing roots of a plant, the oxynaphthylamine is deposited upon the surface of the roots in characteristic zones, as already described by Raciborski.[a] The root cap is slightly, if at all, colored; the zone of primary meristematic cells immediately back of the root cap is marked by a distinct narrow band of color; the zone of actively growing cells in the region of greatest elongation is not intensely colored; the more slowly growing portions of the root possess the purplish color, but it becomes less intense as one passes to the upper parts of the root.

The superior oxidizing power of the meristematic tissues of the plant is not only shown by the narrow zone of deep color formed on the primary meristem of the apical portion of the roots, but also by the small dots of color produced on that portion of the root from which secondary roots arise. If a wheat root 8 to 10 cm. in length is placed in a solution of naphthylamine it will exhibit, in addition to the deeper colored zones near the apex, dark purple spots at the places where secondary roots are forming and are about to break through the cortical layers of the primary root. If secondary roots are already present, they show the same zones of colors already described for the primary roots.

The concentrations of naphthylamine used in solution cultures are necessarily low on account of its slight solubility in water, but are sufficiently strong to show the oxidation. In ordinary practice 10 parts of naphthylamine to a million (10 mg. per liter of water) is a suitable concentration to use. This concentration will eventually retard the growth of wheat plants, but is not detrimental to growth in the length of time usually required to demonstrate the oxidizing powers of the plant roots. A concentration of 5 parts per million sometimes acts as a stimulant to growth.

Benzidine is another chromogen which is oxidized by plants and may advantageously be used to demonstrate their oxidizing action. It is only slightly soluble in water, but in weak, colorless solution it is readily oxidized by plant roots to an insoluble dye which gives the roots a blue-black or black appearance. Benzidine is slightly toxic to plant growth, but does not cause pathological conditions within the time required for demonstrating the oxidizing power of the plant roots. A concentration of 5 parts benzidine to a million of water will give good results and does not injure wheat roots in twenty-four hours, although that concentration may eventually inhibit growth.

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[a] Bul. Acad. Sci. Cracovie, 1905, pp. 338, 668, 693.

The effect of oxidation may easily be demonstrated by allowing the roots of wheat plants to grow in a 5 part per million solution of benzidine for twelve to twenty-four hours. The formation of colors in distinct zones is fully as striking as in the case of alpha-naphthylamine. As before, the root cap does not produce oxidation products, the primary meristem is marked by a narrow band of brown color, the zone of elongation is practically uncolored, whereas the portion of the root just above the zone of greatest elongation is entirely colored blue-black or black by the oxidation products.

Solutions of vanillin and vanillic acid act in much the same manner as those of naphthylamine or benzidine, but the concentrations required to demonstrate the oxidizing power of roots are quite strongly toxic.[a] Both substances are converted by the oxidizing action of the roots into a purple insoluble dye which stains the surface of the roots in the manner previously described. The concentration of vanillin in the solution most favorable for showing oxidation with wheat plants lies between 250 and 500 parts per million. A solution of this concentration will demonstrate the oxidizing power of the roots before the plants become seriously injured. To demonstrate the oxidizing power of roots with vanillic acid, a solution of the latter containing 25 to 50 parts per million should be used.

Esculin is another chromogen belonging to this class, but was found to be less suitable for this work. Esculin solutions when freshly prepared exhibit a blue fluorescence. After plant roots have grown for a few days in such a solution, the blue fluorescence is lost and the roots themselves are colored yellow as a result of their oxidizing activity, the dye formed being insoluble and remaining upon the surface of the roots where the greatest oxidation occurs. The concentrations necessary to demonstrate the oxidizing power of roots range from 500 to 1,000 parts per million and are eventually quite toxic to wheat plants.

The second class of chromogens, viz, those which are converted into soluble coloring matters, are in many respects more useful for oxidation studies than those belonging to the first class, because the intensity of the color, and hence the amount of oxidation, can be quantitatively expressed. The substances belonging to the second class which have been employed in this study are phenolphthalin, aloin, and leuco-rosolic acid. Alcoholic solutions of guaiac were also used for various tests, but could not be put into solution cultures containing growing roots.

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[a] Bul. 47, Bureau of Soils, U. S. Dept. Agr., 1907; Proc. Am. Soc. Biol. Chem., 1, 33 (1907); Bot. Gaz., 45, 73 (1908).

The value of phenolphthalin, a leuco compound prepared from phenolphthalein, as an indicator of oxidizing enzymes, has been demonstrated for plant work by Kastle[a] and by Raciborski.[b] Phenolphthalin is prepared by the method described by Baeyer,[c] which consists in reducing ordinary phenolphthalein with zinc dust and sodium hydroxide to phenolphthalin. The latter substance is oxidized back to phenolphthalein by the oxidizing power of the plant roots, a change which is readily demonstrated when the solution is rendered alkaline. The following procedure was observed in preparing this reagent: Weigh out 250 mg. of phenolphthalein, 3 grams sodium hydroxide, and 4 or 5 grams of zinc dust. Place all in a flask and add 100 to 150 c. c. of water. Place the flask on a sand bath and heat sufficiently to cause a rapid evolution of hydrogen without causing the contents of the flask to boil violently. The heating usually requires two to three hours to effect reduction of the phenolphthalein. The contents of the flask, after reduction is completed, may be filtered and rendered nearly neutral with hydrochloric acid and may then be used as indicator in the plant cultures. However, better results may be obtained by using phenolphthalin purified according to the method given by Baeyer. After purification the phenolphthalin is dissolved in N/10 or N/20 NaOH and a few cubic centimeters of the alkaline solution put into each culture. If quantitative results are desired, it is necessary to reduce all the solution cultures to neutrality or the same degree of alkalinity. A very slight degree of alkalinity is not usually harmful to plants within the duration of an experiment and is favorable to the process of oxidation. Phenolphthalin is slowly oxidized by mere contact with the air; therefore it is advisable to install controls which will allow the results to be corrected for this atmospheric oxidation. When the phenolphthalin is added to the solution cultures, a like quantity is therefore added to jars of distilled water equal in volume to the cultures. The amount of oxidation in these blanks is subtracted from what is observed in the plant cultures.

Plant cultures usually show striking results at the end of ten to twenty hours, depending somewhat upon the temperature and amount of root surface. At the end of the experiment the plants are removed from the cultures and all are rendered distinctly alkaline with sodium hydroxide solution and thus the red phenolphthalein color is developed.

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[a] Am. Chem. Jour., **26**, 526 (1901); Bul. 26, Hyg. Lab., U. S. Pub. Health and Mar. Hosp. Service, 1906.

[b] Bul. Acad. Sci. Cracovie, math.-nat. Cl., 1905, 338.

[c] Ann. Chem., **202**, 80 (1880).

The great advantage in the use of phenolphthalin to demonstrate the oxidizing power of roots lies in the fact that it is capable of yielding quantitative results. After the colors have been developed in the alkaline solution their intensities may be estimated by the aid of a colorimeter. In the work reported below the color intensities were estimated by means of the colorimeter previously described,[a] which permits of rapid and accurate readings. The colored solutions may be read against a standard phenolphthalein solution or against a standard Lovibond red glass slide.[b] The readings of the colorimetric tubes are inversely proportional to the color intensity and are easily reduced to their relative values.

Aloin is a substance which may be used to demonstrate the oxidizing power of roots in the same way as phenolphthalin is used. Aloin, or barbaloin, is the active principle of Barbadoes aloes and is obtained in the market in the form of a yellow powder, fairly soluble in water and serving well as an indicator of the oxidizing power of plants. At the concentrations used in our work it was not found to exert any toxic action upon plants. As a result of a limited investigation of the chemistry of aloin it seems that its value as an indicator of the oxidizing power of plants depends largely upon the content of iso-barbaloin.

When oxidized by the plant roots, the aloin solution is changed from a pale yellow color to a permanent deep wine-red color similar to that given by Klunge's reaction for iso-barbaloin. Klunge's reaction[c] consists in dissolving aloin (containing iso-barbaloin) in a 15 per cent sodium chloride solution and adding 5 c. c. of concentrated copper sulphate solution. Almost immediately the yellow, straw-colored solution begins to change to a permanent deep wine red. The change is hastened by warming the solution.

When experimenting with plant juices containing enzymes there appears to be a difference between the reactions to aqueous and alcoholic solutions of aloin. As the results of experiments described in detail in a subsequent section of this paper, it was found that an aqueous solution of aloin is a better indicator of the presence of oxidase, while an alcoholic solution of aloin is the better indicator of peroxidase.

Aloin, like phenolphthalin, should be added to neutral or faintly alkaline culture solutions, and where quantitative results are desired all solutions should be of the same degree of alkalinity. In all of our work aloin was added at the rate of 100 mg. of aloin to 250 c. c. of culture solution. If actively growing seedlings are used in a very faintly alkaline solution, a small amount of red color may be developed in an hour or two, but the experiments should be continued for twelve to twenty hours for the final observation. When certain inorganic salts were present in the culture solutions, the aloin red color was slightly modified. The addition of nitrates or previous treatment of the soil extracts with an absorbing agent gave the oxidized aloin a purplish tinge, resembling that of fresh fuchsin solution. The presence of calcium carbonate gave a purer red color, resembling alkanna or cochineal solution.

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[a] Jour. Am. Chem. Soc., **27**, 1192 (1905); Bul. 31, Bureau of Soils, U. S. Dept. Agr., 1906.

[b] Lovibond, Jour. Soc. Chem. Ind., **13**, 308 (1894); see also Schreiner, Pharm. Review, **19**, 61 (1901).

[c] Schweizerische Wochenschr. f. Pharm., **21**, 1 (1883); also Leger, Compt. rend., **131**, 55 (1900).

The fact that aloin is changed by oxidation from a light yellow to a deep red solution makes it somewhat more difficult to obtain colorimetric readings than in the case of phenolphthalin, where there is a change from a colorless to a red solution. It is nevertheless practical to use the colorimeter for measuring approximately the intensity of color in aloin solutions by arranging the solutions in the order of their apparent color intensities and using each solution first as an unknown and then as a standard for the next higher. For example, let No. 1, the weakest color, be the standard against which No. 2 is read. Then discard No. 1, set No. 2 at a convenient mark, and, using it as the standard, read No. 3. In turn No. 3 is used as the standard for No. 4, and so on. In this way one avoids the necessity of comparing a solution strongly tinged with yellow against a solution which contains little or no yellow tint. In any two solutions to be estimated the tints of yellow should not be greatly different.

Leuco-rosolic acid is another reagent which is useful for demonstrating the oxidizing power of plant juices[a] and plant roots. When a few cubic centimeters of a slightly alkaline, colorless solution are added to a culture containing plants, the leuco-rosolic acid is oxidized back to rosolic acid, the change being shown by the appearance of the red color. This reagent is not so generally useful as phenolphthalin and aloin, since it is more readily oxidized by mere contact with the air, as well as being more difficult to prepare.

PRELIMINARY EXPERIMENTS.

The first experiments were conducted for the purpose of ascertaining some general facts concerning the phenomenon of oxidation by the roots of seedlings, as well as to learn the methods best suited for studying oxidation in soil extracts. The experiments of Raciborski dealt with plants growing under what may be termed pure culture conditions, and those of Kastle were concerned with the oxidizing power of plant extracts.

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[a] Kastle, J. H., Bul. 26, Hyg. Lab., U. S. Pub. Health and Mar. Hosp. Serv., p. 17 (1906).

In the first experiment wheat seedlings 4 days old were placed in solutions of alpha-naphthylamine having concentrations of 1, 2, 5, and 10 parts per million, and in a solution of 5 parts per million benzidine. The experiment was set up at 4 p. m., and observations were made eighteen hours later. At the expiration of that time colors could be distinctly seen on the white surface of the wheat roots. The roots in the solution of 1 part per million naphthylamine were pale lavender; in 2 parts per million they were pronounced lavender, except at the root cap; in the 5 parts per million solution they were violet in the region occupied by the primary meristem, and in the region of the root hairs where growth of elongation occurs; the root-cap and a narrow zone just above the primary meristem were uncolored; in the 10 parts per million solution the roots showed the same colors as in that of 5 parts per million. The roots in the solution of 5 parts per million of benzidine showed their power of oxidation by the formation of brown-violet color distributed in the same manner as described for the roots which grew in the solutions of naphthylamine.

In order to learn whether the oxidizing powers of roots were affected by conditions which favor growth, and also whether the method used in the first experiment would show such differences, the following experiment was made: Three water cultures were made, in each of which an equal number of wheat seedlings of uniform age and size were employed. One culture was made with redistilled water, the second with an aqueous extract of a rich garden soil, the third with a dilute aqueous extract of well-decomposed stable manure. After the plants had grown for one day in these liquids the oxidizing powers of the plants were determined by transferring them to other bottles containing 2 parts per million of alpha-naphthylamine in distilled water. At the expiration of eighteen hours the intensity of the purple colors showed that the roots which had previously grown in the extract of garden soil had oxidized more naphthylamine than those which had grown in distilled water, and those which had grown in manure extract had oxidized more naphthylamine than those from the garden soil extract. At the end of twenty-four hours the differences in color intensity in the two cultures were still more marked.

The next experiment was an attempt to employ a method which would permit a more accurate quantitative expression of the oxidizing power of the roots. Two cultures of wheat seedlings were grown for five days in an extract of unproductive soil under the same conditions as two other cultures in an extract of rich garden soil. Each culture contained 60 c. c. of the respective soil extract. The oxidizing power of the roots was, in this experiment, shown by using phenolphthalin. The phenolphthalin was prepared by the method given in a previous paragraph and 0.4 c. c. of the freshly prepared solution added to each culture of plants after they had grown five days in their respective solutions. Nineteen hours after adding the indicator all plants were removed from the cultures and the solutions rendered alkaline, thus producing the phenolphthalein color. The solutions were brought to the same volume by the addition of distilled water, and the relative amount of oxidation was measured by determining the color intensities of the different cultures.

The two cultures of poor soil gave readings of 40 and 42 divisions on the graduated tube against slide No. 2 (Lovibond system); the two cultures of rich garden soil gave readings of 14 and 24 divisions against slide No. 4 (Lovibond system). Averaging the readings and comparing the intensity of the colors, the oxidation in the poor lawn soil and in the rich garden soil stands in the ratio of 1 to 4, or more exactly as 19 to 82. This result indicated that a procedure based upon this method will give satisfactory quantitative results.

This method was further tested by another experiment, in which different beneficial treatments were applied to an extract of the unproductive soil used in the last experiment. The results of the last experiment showed that the oxidizing power of plants growing in solutions of different physiological properties varies considerably, but left the question open as to how much of the oxidation result might be due to plants and how much to the solution. In the present experiment, therefore, two of the four bottles in each set of solutions were left unplanted and their oxidizing powers measured along with those of the solutions which contained plants. The treatment applied consisted in adding fertilizer substances in the form of pure chemicals. Calcium carbonate was added at the rate of 2,000, and sodium nitrate at the rate of 50 parts per million, respectively. The cultures were put up August 24 and allowed to grow until August 28, when the amount of water transpired by each culture was ascertained and 3 c. c. of a freshly prepared phenolphthalin solution added to each bottle. After root oxidation had taken place the color of the phenolphthalein was brought out by adding a few drops of strong alkali to each culture and the intensities of the different solutions compared in the colorimeter. Table I presents the figures which give the relative amount of oxidation in the planted and unplanted solutions. When the phenolphthalin solution was added to the culture jars the same quantity was added to a jar of distilled water, which served as a control upon the oxidation incident to contact with atmospheric oxygen. The color intensity of this control was determined and subtracted from each of the other readings.

TABLE I.—*Relative oxidizing power of cultures and unplanted solutions of Takoma lawn soil extract, with and without the addition of fertilizer ingredients. Oxidizing power of plants grown in distilled water used as the basis of comparison.*

[P. p. m.=parts per million.]

No.	Culture.	Relative oxidation.
1	Distilled water (planted) Average	100
2	Distilled water (planted)	
3	Extract Takoma lawn soil (planted)	88
4	Same (planted)	74
5	Same (unplanted)	8
6	Same (unplanted)	19
7	Same +2,000 p. p. m. $CaCO_3$ (planted)	113
8	Same (planted)	63
9	Same (unplanted)	19
10	Same (unplanted)	25
11	Same +50 p. p. m. $NaNO_3$ (planted)	98
12	Same (planted)	63
13	Same (unplanted)	24
14	Same (unplanted)	17

The plants used in this experiment were quite young and the experiment was only continued for four days, a period rather too short for the maximum oxidation effect, as shown by subsequent experiments; nevertheless the results show that the different treatments affected the oxidizing powers. The plants grown in extracts of poor soil possessed less oxidizing power than the controls in distilled water, but the oxidizing power was increased by the addition of calcium carbonate. The addition of sodium nitrate did not show any marked increase in the oxidation in those solutions within the time of the experiment, although its effect as shown in later experiments is always to increase oxidation.

The point which is to be emphasized in this experiment and which has not been previously brought out is that the soil extract unplanted possesses a comparatively feeble power of oxidation, as shown by the use of phenolphthalin, and that the addition of calcium carbonate and sodium nitrate slightly increased this small oxidizing power.

An additional experiment was performed, using three different salts in distilled water. The results of this experiment, which are given in Table II, confirm those of the foregoing experiments in the soil extract. The cultures were made in duplicates, and the figures represent the averages of each pair.

TABLE II.—*Relative oxidizing power of cultures and unplanted solutions of three nutrient salts. Oxidizing power of plants grown in distilled water used as basis of comparison.*

[P. p. m.=parts per million.]

No.	Culture.	Relative oxidation.
1	Controls in distilled water (planted)	100
2	Solution, 50 p. p. m. NO_3 as $NaNO_3$ (planted)	282
3	Same (unplanted)	39
4	Solution, 35 p. p. m. K as KCl (planted)	72
5	Same (unplanted)	36
6	Solution, 50 p. p. m. PO_4 as $NaHPO_4$ (planted)	88
7	Same (unplanted)	21

The enzymotic nature of the oxidizing process was next investigated, using alcoholic guaiac. When alcoholic guaiac is added to a solution in which wheat roots have been growing for a time, evidence of the presence of peroxidase was obtained, but none for oxidase.

When young growing wheat roots are treated with a solution of alcoholic guaiac they instantly give a blue color, which deepens when hydrogen peroxide is added. This indicates that the cells of the plant root contain an oxidase, as Czapek has also shown.[a]

A word may be introduced at this place concerning the possible function of bacteria in producing oxidizing ferments which might accomplish some of the effects noted. It is, of course, possible that such organisms existed in the culture employed, since after filtering the extracts no especial precautions were taken to keep them sterile and microorganisms which were on the roots of the plants would be introduced into the solutions. That these microorganisms were responsible for any appreciable amount of oxidation in the experiments described in this paper is hardly possible. In the first place the solutions used were not well adapted for a very thrifty development of micro-organisms, as was shown by their freedom from turbidity, odors, or other indications. The definite zones of color produced when indicators like alpha-naphthylamine and benzidine were used and their close correspondence to definite zones of tissue in the root show that the oxidation is performed only by agents intimately connected with the roots. The colors due to oxidation were most intense on the regions of the root where growth was most active, whereas we would expect that the bacteria, if zonally distributed, would be more abundant on the dying cells of the root cap or the dismantled cortical layers of the older parts of the root. It seems, therefore, highly improbable that the oxidizing activities of microorganisms can be responsible to any appreciable extent for the results observed.

OXIDATION IN SOIL EXTRACTS.

Following the preliminary experiments already described, further experiments were made to study in more detail the oxidizing power of plants grown in extracts of soil of different character. These experiments were chiefly designed to study the oxidizing powers of plants in extracts of good and poor soils, of extracts treated with absorbing agents, and in distillates of soil extracts.

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[a] Ann. of Bot., **19**, 75 (1905).

The difference in the oxidizing power of plants in extracts of fertile and infertile soils is shown by the following experiments. In the first experiment an extract of Takoma lawn soil was compared with an extract of good Leonardtown loam. The former is a very unproductive soil and the latter is a much better and usually very productive soil. The oxidizing powers of the plants were determined by adding phenolphthalin to the cultures after the plants had grown in them for nine days. The growth and oxidizing powers of the plants are shown in Table III, relative to control cultures made in distilled water, which are represented as 100 in each case.

Table III.—*Comparative growth and oxidizing powers of plants in extracts of Takoma lawn soil and good Leonardtown loam. Growth expressed in terms of relative transpiration.*

No.	Culture.	Relative growth.	Relative oxidation.
1	Controls in distilled water	100	100
2	Extract Takoma lawn soil	33	72
3	Extract Leonardtown loam	50	286

In the comparatively short time of this experiment during cloudy winter weather, December 10 to 19, the plant growth as manifested by the figures for transpiration did not have time enough to show the relative productiveness of the two extracts, since it has usually been found that the Leonardtown loam extract produces in fourteen to eighteen days better plants than distilled water. The figures do show, however, a much greater oxidizing power in the plants grown in the extract of the more fertile soil even under these conditions.

Subsequent experiments were performed, the results of which corroborated the foregoing. In each case where growth was good there was also good oxidation; where growth indicated a poor soil extract the oxidation was small, as will be seen from Tables IV and V.

Table IV.—*Comparative growth and oxidizing powers of plants in extracts of poor sandy loam and garden loam. Growth expressed in terms of relative transpiration.*

No.	Culture.	Relative growth.	Relative oxidation.
1	Controls in distilled water	100	100
2	Extract poor sandy loam	77	103
3	Extract garden loam	125	275

TABLE V.—*Comparative growth and oxidizing powers of plants in extract of good and poor soils. Growth expressed in terms of relative transpiration.*

No.	Culture.	Relative growth.	Relative oxidation.
1	Controls in distilled water	100	100
2	Extract Arlington clay loam	75	107
3	Extract Clarksville silt loam	123	133
4	Extract Stockton peat	272	400

In all these experiments where direct comparisons are made between the extracts of soils that are so poor as to give less plant growth than pure distilled water and other extracts giving materially greater growth than pure distilled water, it appears to be unmistakably true that the cultures made of extracts of good, fertile soils possess much greater oxidizing powers than those made of extracts of soils of relatively less fertility.

The next question considered was concerned with the effect of treating the soil extract with absorbing agents. Treating the extracts of a more or less unproductive soil with carbon black or other good absorbing agent is usually beneficial to growth. This response seems to be quite general for all poor-soil extracts, although their response to other treatments may be quite different. Previous work in this laboratory[a] has shown that this ameliorating action is due to the removal of deleterious organic substances. Experiments were accordingly made in which a number of different soil extracts were treated with carbon black or ferric hydrate. The absorbing agent was shaken with the soil extract and filtered off at the expiration of a half hour in the same manner as the distilled water used in the experiments was prepared. The relative effect of this treatment upon growth and the oxidizing power of the plants is shown in Table VI, where the effect in the untreated-soil extract is in each case taken as 100.

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[a] Buls. 28, 36, and 40, Bureau of Soils, U. S. Dept. Agr.; Breazeale, J. F., Bot. Gaz., 41: 54 (1906).

TABLE VI.—*Effect of treatment with carbon black and ferric hydrate upon growth and oxidizing power of plants grown in extracts of various soils. Growth expressed in terms of relative transpiration.*

No.	Culture.	Relative growth.	Relative oxidation.
1	Arlington clay loam[a]	100	100
	Same, treated with carbon black	124	265
2	Takoma lawn soil[a]	100	100
	Same, treated with carbon black	137	100
3	Alloway clay[a]	100	100
	Same, treated with carbon black	116	117
4	Dunkirk sandy loam[a]	100	100
	Same, treated with carbon black	112	280
5	Miami silt loam[a]	100	100
	Same, treated with ferric hydrate	171	198
6	Marshall clay loam[b]	100	100
	Same, treated with carbon black	216	130
7	Clarksville silt loam[b]	100	100
	Same, treated with carbon black	450	227
8	Elkton silt loam[b]	100	100
	Same, treated with carbon black	179	317
9	Cecil fine sandy loam[b]	100	100
	Same, treated with carbon black	112	200
10	Hagerstown loam[b]	100	100
	Same, treated with carbon black	230	500
11	Cecil sandy loam[b]	100	100
	Same, treated with carbon black	193	241
12	Dutchess silt loam[b]	100	100
	Same, treated with carbon black	110	373
13	Poor sandy loam[b]	100	100
	Same, treated with ferric hydrate	170	584
14	Garden loam[b]	100	100
	Same, treated with ferric hydrate	136	318

[a] Phenolphthalin used in estimating oxidation.
[b] Aloin used in estimating oxidation.

It will be noted that in all but one of the soil extracts the effects of the treatment with an absorbing agent strongly increased the oxidizing powers of the plants subsequently grown in the extract. The treatment also increased the growth of the plants, as shown by the transpiration.

The increased oxidation, as well as the increased growth, points directly to the conclusion that the soil extracts have been so improved by the treatment given as to induce a more active functioning of processes necessary to secure the best conditions for growth. In the single case of No. 2 the growth was increased as a result of the treatment with carbon black, but the oxidation was not. This result was frequently obtained with the Takoma lawn soil; in some cases the oxidizing power was even slightly decreased as a result of treatment with absorbing agents, although growth was increased. No satisfactory explanation has as yet been obtained for this apparently exceptional action. It may be found upon further investigation that the lack of response was due to the presence of matter inhibiting oxidation, which was not removed by the carbon black. This question seems worthy of more study than we have been able to give it.

Extracts of poor soils sometimes contain volatile bodies of a deleterious nature which can be driven off by boiling and collected in the distillate. The writers have described the behavior of plants grown in such distillates. In these cases the distillate usually exhibits the same toxic properties which the original extracts possessed and the residue is correspondingly improved.

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[a] Bul. 40, Bureau of Soils, U. S. Dept. Agr., 1907.

To study the effects of these distillates upon the oxidizing powers of the plants, the following experiments were made: One liter of such a soil extract was placed in a distilling apparatus and distilled until 200 c.c. of distillate had passed over and been condensed. This fluid was made up to 500 c.c. by adding water and designated "First portion." When a second 200 c.c. of distillate had been collected, it was likewise made up to 500 c.c. and designated "Second portion." Cultures were made in each portion, together with controls in pure distilled water. At the end of a week the plants in the different solutions showed marked differences. The plants in the first portion of the distillate were very small and were dying; those in the second portion were much better; in fact were equal to the controls growing in distilled water. One hundred milligrams of aloin was added to each of the culture bottles and on the following day the amount of oxidation was noted by comparing the intensity of red color in each culture. The cultures in the "First portion" showed much less oxidation than either of the other two. The most oxidation appeared to have gone on in the cultures in the "Second portion," which was slightly in excess of that in the control cultures in pure distilled water.

The question was studied further and in a more quantitative manner by the following experiment: An extract of Elkton silt loam, having a volume of 750 c.c., was placed in a flask connected with a condenser and distilled. The distillate, amounting to 500 c.c., was collected in two portions of 250 c.c. each and used as a culture medium in which plants were grown, together with the residue in the distilling flask, which was diluted to its original volume and also used for growing plants. For comparison, cultures were also made in the original soil extract. The wheat plants were allowed to grow in the various solutions for 13 days and then their oxidizing powers were estimated by means of phenolphthalin. The growth and oxidation are shown in Table VII.

TABLE VII.—*Growth and oxidation in distillate and residue of Elkton silt loam. Growth expressed in terms of relative transpiration.*

No.	Culture.	Relative growth.	Relative oxidation.
1	Original soil extract untreated	100	100
2	First portion of distillate	53	20
3	Second portion of distillate	70	19
4	Residue after distillation, diluted to original volume	132	180

These results show that the distillates of this soil extract were less favorable for growth and oxidation than the original untreated soil extract, while the residue from distillation was materially improved. This seems to indicate that the original soil extract, like others which have been investigated,[a] contained a volatile toxic substance which inhibited oxidation by the roots, and that this substance was driven off by the process of distillation with resulting benefit to oxidation in the residue. Judging from the growth of the plants the first portion of the distillate contained a larger proportion of this deleterious substance than the second, although this smaller amount appears to be equally as deleterious to the oxidizing powers of the roots as the larger amount present in the first portion. The oxidizing power of the plants in the residue was much greater than in the distillates or in the original soil extract.

Evidently the oxidizing powers of the roots are affected by certain exterior conditions, since an improvement in the physiological properties of the soil extract results in increased oxidation and the presence of deleterious bodies results in decreased oxidation.

From the experimental results thus far presented it appears that the oxidizing power of the soil extracts themselves can be regarded as partly, but not mainly, responsible for the oxidation observed in the experiments. In one of the preliminary experiments reported in Table I it was shown that the soil extract after filtration through a Pasteur-Chamberland filter tube exhibited some oxidation, even when no plants were growing. It was likewise shown by the results in Table II that certain nutrient salts dissolved in distilled water were able to accomplish a material amount of oxidation without the presence of growing plants. It therefore seems unlikely that any considerable amount of oxidation was performed by microorganic growth. If we consider the result in this last experiment, where oxidation was increased in the residue from distillation after continued boiling, it seems that any extensive action, not only of microorganisms, but also of enzymes, must be precluded. In the soil, however, it is quite probable that both of these oxidizing factors would come into play, but it is quite certain that the oxidizing power of the roots would accomplish a considerable portion of the oxidation observed.

INFLUENCE OF VARIOUS SALTS UPON OXIDATION.

The next step in the investigation consisted in a study of the influence of various fertilizer ingredients upon the processes of oxidation already demonstrated. It is a fact recognized in the practice of agriculture that certain substances, such as lime or gypsum, employed as fertilizers produce beneficial results disproportionate to their possible function as nutrients. Also, that substances possessing high value as nutrients produce beneficial effects even when analysis shows that both soil and plant already contain comparatively large amounts of the identical element in question.

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[a] Buls. 28, 36, and 40, Bureau of Soils, U. S. Dept. Agr.

When this point was reached the inquiry naturally presented itself as to whether the various fertilizer ingredients used for increasing plant growth had an effect upon the oxidizing powers of the roots growing in solutions or soil extracts to which the salts had been added. For the purpose of studying these effects the chemically pure salts were added to extracts of soils which were known to be improved for plant growth by the addition of the salts in question. Wheat plants were grown in the soil extracts for eight to fourteen days by the culture method previously described; then the oxidizing power of the culture solutions (with the plants in them) was tested by adding a suitable chromogen and quantitatively determining the intensity of the colors resulting from the oxidation of the chromogen.

The first class of compounds whose action was studied was that containing nitrogen. The application of nitrogenous compounds to the medium usually produces a beneficial effect upon the plants grown in it. The agricultural problem of fertilization for many soils lies in the selection and application of suitable forms of nitrogen. It has been found profitable, accordingly, to study the effect of certain salts which are known to act more or less beneficially upon the growth of plants in soil and solution cultures. In practice the inorganic compounds most commonly used are sodium nitrate and ammonium sulphate.

A comparative study of the effects of different forms of nitrate was made upon Arlington clay loam, a soil which has been found to respond to the application of nitrates. The sodium, potassium, and calcium salts were used, selecting amounts which gave equal concentrations of NO_3 in each solution. The increase in oxidizing powers due to the addition of the nitrates is shown in Table VIII, where the increases in growth are also shown for the sake of comparison.

TABLE VIII.—*Relative growth and oxidizing power resulting from the addition of different forms of nitrate to extract of Arlington clay loam. Growth expressed in terms of relative transpiration.*

[P. p m.=parts per million.]

No.	Culture.	Relative growth.	Relative oxidation.
1	Soil extract untreated	100	100
2	Same + 100 p. p. m. NO_3 as Na NO_3	116	180
3	Same + 100 p. p. m. NO_3 as KNO_3	182	104
4	Same + 100 p. p. m. NO_3 as Ca $(NO_3)_2$	198	112

The results of this experiment, which indicate that potassium nitrate is less favorable to the oxidation processes than sodium nitrate or calcium nitrate, was supplemented by another experiment with sodium and potassium nitrate upon three different soil extracts.

TABLE IX.—*Percentage increase in oxidation resulting from the addition of nitrate, as sodium nitrate and potassium nitrate, to various soil extracts.*

No.	Culture.	Increase due to addition of $NaNO_3$.	Increase due to addition of KNO_3.
1	Miami black clay loam	58	−20
2	Penn clay	50	66
3	Lyons silt loam	62	38
	Average	57	28

The outcome of these experiments is supported by the results of many which follow in subsequent pages, showing that potassium salts are less favorable to oxidation than either the sodium or calcium salts of the same acid. Concerning the comparative effects of sodium and calcium the data are not sufficient to allow of any general statements.

The comparative effects of various forms of nitrogen were shown by an experiment employing three different nitrates in the extract of Cecil sandy loam. The nitrate was added in each case at the rate of 50 parts per million of NO_3 (11.3 parts of N). By previous experiments it had been found that this soil was beneficially affected by the addition of nitrogenous fertilizers. The effect of these salts upon the growth and oxidizing power of plants grown in the soil extract is shown in Table X.

TABLE X.—*Effect of nitrates upon growth and oxidation in extract of Cecil sandy loam. Growth expressed in terms of relative transpiration.*

No.	Culture.	Relative growth	Relative oxidation.
1	Extract Cecil sandy loam	100	100
2	Same + sodium nitrate (11.3 p. p. m. N.)	197	147
3	Same + potassium nitrate (11.3 p. p. m. N)	152	90
4	Same + calcium nitrate (11.3 p. p. m. N)	170	280

In this experiment, as in the preceding, potassium nitrate, although materially increasing growth, was slightly unfavorable to oxidation; but sodium and calcium nitrate were both responsible for considerable increase in oxidation.

An experiment to show the comparative action of sodium nitrate and ammonium sulphate was made, using an extract of Arlington clay loam. This experiment ran eleven days, and the oxidation was estimated at its termination by the use of phenolphthalin. The percentage increases in growth and oxidation caused by the addition of sodium nitrate were 90 and 38, respectively; the increases due to the addition of ammonium sulphate were 16 and 13, respectively. From these data it appears that the beneficial action of ammonium sulphate in solution culture was slight in respect to both growth and oxidation.

In the next experiment upon the action of nitrogenous bodies, sodium nitrate was added to extracts of soils obtained from various localities. The list of soils is given in Table XI, where the effects of the nitrate upon growth and oxidation is expressed by figures, which show the percentage increase in each case over the untreated soil extract.

Table XI.—*Percentage increase in growth and oxidizing power of plants resulting from the addition of sodium nitrate to various soil extracts. Growth expressed in terms of relative transpiration.*

No.	Culture.	Percentage increase in growth.	Percentage increase in oxidation.
1	Arlington clay loam (average of 4 experiments)	21	69
2	Miami black clay loam (average of 2 experiments)	19	86
3	Penn clay	−25	50
4	Lyons silt loam	81	62
5	Clarksville silt loam	40	12
6	Elkton silt loam	29	115
7	Cecil fine sandy loam	12	25
8	Hagerstown loam	12	49
9	Dutchess silt loam	4	− 34
10	Cecil sandy loam	109	221
	Average	30.2	60.5

With one exception the experiments summarized in the above table all show a marked increase in oxidizing activity accompanying the addition of sodium nitrate to the soil extract. This is especially striking in No. 3, where in the duration of the experiment the growth of the plant was not increased by the presence of the nitrate, but actually retarded; nevertheless the oxidation was in this case distinctly increased. The average result shows an increase in oxidation of 60.5 per cent as the effect of adding sodium nitrate to the soil extracts. It will be noted that the relation between the growth and oxidizing power is not a constant one, although when one is increased the other usually shows an increase. From our present knowledge of the processes affected by the presence of such a salt as sodium nitrate this result is not inconsistent. In the first place the nitrogen is capable of increasing growth because it is taken up by the plant and enters directly into the composition of important constituents of the protoplasm. By increasing growth and simultaneously accelerating various vital processes in the plant, it is quite probable that the production and secretion of peroxidase would be thereby increased, but it is probable that the salt would have also a direct action upon the peroxidase in the solution, as will be subsequently shown.

The addition of calcium carbonate to culture solutions in which plants are growing usually results in a great increase in root development. This effect of calcium salts, which was first shown by Wolf,[a] has also been shown to hold for plants grown in soil extracts by the writers,[b] with the further observation that the transpiration of wheat plants is markedly increased by the addition of calcium carbonate.

In studying the effect of this salt upon the oxidizing power of roots, it was added to the extracts of various soils which responded in a greater or less degree to the application of lime in the field or in pots. The salt was added to the soil extracts at the rate of 2,000 parts of calcium carbonate to a million of solution at the time of installing the young plants. There was always some undissolved salt in the bottom of the culture bottles and this may have increased root growth slightly as a result of its power to absorb deleterious substances.

The percentage increase in growth and oxidation due to the addition of calcium carbonate to four different soil extracts are shown in Table XII.

Table XII.—*Percentage increase in growth and oxidation resulting from the addition of calcium carbonate to various soil extracts. Growth expressed in terms of relative transpiration.*

No.	Culture.	Percentage increase in growth.	Percentage increase in oxidation.
1	Cecil fine sandy loam	34	150
2	Hagerstown loam	94	250
3	Dutchess silt loam	12	91
4	Cecil sandy loam	96	484

The addition of this substance materially increased not only the growth of the plants but also their oxidizing powers. The amount of increased oxidation seems more nearly comparable to that arising from treating the soil extracts with absorbing agents like carbon black and ferric hydrate than to any other treatment used in these experiments.

Further observations upon the oxidizing power of plants in solutions containing calcium carbonate showed that it caused more or less oxidation of the chromogen independently of plant action. A part of this alteration was due to the fact that in the slightly alkaline solutions there was more rapid oxidation by atmospheric oxygen. The oxidation due to the mere presence of the calcium carbonate in the extract was, however, not found to be sufficient to account for the results which have been recorded in Table XII. As a means of comparison, experiments were made using other salts of calcium.

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[a] Landw. Vers-Stat., **6**, 203 (1864).

[b] Bul. 40, Bureau of Soils, U. S. Dept. Agr.; Jour. Am. Chem. Soc. **30**, 85 (1908).

The nitrate, carbonate, and sulphate of calcium were added to different portions of an extract of Cecil sandy loam which were used as culture solutions for plants. The calcium nitrate was added at the rate of 66 parts per million, the calcium carbonate in excess of solubility as before, and the calcium sulphate at the rate of 200 parts per million. Table XIII presents the effect of these salts upon growth and oxidation, expressing that of the control as 100.

TABLE XIII.—*Relative growth and oxidation in extract of Cecil sandy loam due to the addition of calcium nitrate, carbonate, and sulphate. Growth expressed in terms of relative transpiration.*

[P. p. m.=parts per million.]

No.	Culture.	Relative growth.	Relative oxidation.
1	Soil extract untreated	100	100
2	Same + 66 p. p. m. $Ca(NO_3)_2$	173	207
3	Same + $CaCO_3$ (excess)	214	192
4	Same + 200 p. p. m. $CaSO_4$	194	497

From the above results it seems quite certain that the beneficial action of calcium carbonate upon oxidation is not primarily due to its alkalinity. It will be noted that calcium carbonate was responsible for somewhat greater growth than either of the other two calcium salts added, yet the relative oxidizing power of the cultures to which it was added was no greater than the others—in fact was slightly less than that of the calcium nitrate and much less than that of the neutral calcium sulphate.

In the study of the effect of potassium salts on oxidation these salts were added directly to the soil extracts at the rate of 35 parts of potassium per million of solution. Experiments were made with the two forms of potassium which are most frequently used in agricultural practice, viz, sulphate and chloride. The effect of these salts upon oxidation is given in Tables XIV and XV.

Potassium salts affect the growth of wheat plants differently from most other salts. It has been noted in all of the work in which wheat plants have been used that potassium sulphate or chloride usually favors the growth of the tops of the plant much more than the roots. In fact, the improvement in growth is often manifested only by the tops, while the roots make no better growth than in the untreated soil extracts. Coincident with this relation lies the diminished transpiration which is exhibited by the plants in solutions containing the potassium salts, the amount of water transpired per unit of green weight produced being considerably lower than that required for a unit of green weight in the control cultures.[a] This effect of potassium salts is so great that in reporting this series of experiments it was found better to use the green weight of tops than the transpiration.

Table XIV.—*Percentage increase in growth and oxidation resulting from the addition of potassium as potassium sulphate to extracts of various soils. Growth expressed in terms of relative green weight of tops.*

No.	Culture.	Percentage increase in growth.	Percentage increase in oxidation.
1	Arlington clay loam	2	−27
2	Miami black clay loam	25	7
3	Penn clay	5	17
4	Lyons silt loam (average of 3 experiments)	14	48
5	Merrimac fine sandy loam	1	−27
6	Marshall clay loam	27	0
7	Hagerstown loam	8	8
	Average	11.7	3.7

Table XV.—*Percentage increase in growth and oxidation resulting from the addition of potassium as potassium chloride to extracts of various soils. Growth expressed in terms of relative green weight of tops.*

No.	Culture.	Percentage increase in growth.	Percentage increase in oxidation.
1	Arlington clay loam	26	27
2	Miami black clay loam	11	−6
3	Penn clay	0	29
4	Lyons silt loam (average of three experiments)	31	58
5	Merrimac fine sandy loam	80	−21
6	Clarksville silt loam	8	−9
7	Elkton silt loam	11	−5
8	Cecil fine sandy loam	17	−45
9	Hagerstown loam (average of two experiments)	19	−8
10	Cecil sandy loam	24	−20
	Average	22.7	0

The influence of potassium salts upon the oxidizing powers of plant cultures appears to differ in several ways from that of the two compounds just described. This may in part be the natural result of the way in which potassium salts affect the growth of wheat plants, as pointed out above.

The results reported in these tables show quite conclusively that the effect of potassium salts on the soil extracts named was not beneficial to oxidation. In a majority of the cases where potassium chloride was added there was less oxidation than in the untreated soil extract, although on the whole the response in plant growth was greater than when potassium sulphate was applied to the soil extracts. The result of the ten experiments shows that potassium chloride was quite beneficial to growth, but its general effect was to diminish oxidation in these soil extracts. In the seven experiments upon the effect of potassium sulphate, practically the same conditions were found to prevail. It is true that oxidation was usually greater than in the untreated extracts, but in comparison with the increase produced by sodium nitrate or calcium carbonate the average effect must be regarded as very small.

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[a] See also Hartwell, Wheeler, and Pember, 20th Report, R. I. Agr. Expt. Sta., p. 290 (1907).

The question arises, especially in view of the influence which acid conditions are later shown to exert upon these oxidizing enzymes, whether the small amount of oxidation may not be due to acid conditions in the soil extracts to which potassium salts were added. The plants, as the result of their power of selective absorption, withdrew potassium from the solution more rapidly than they drew sulphate or chlorides, thereby producing slightly acid conditions in the originally neutral solution. This question was answered in the negative by three different experiments. In the first place, by neutralizing the culture solution containing these salts before testing its oxidizing powers the oxidizing power was still low.

Another line of evidence was afforded by comparing the increases in oxidation due to the addition of three different salts of potassium, namely, the nitrate, chloride, and sulphate. When plants are grown in a solution containing potassium nitrate, they remove the acid radical more rapidly than the basic, although both are readily taken up. As a result the solution of KNO_3 becomes slightly alkaline, while KCl and K_2SO_4 solutions would, as just pointed out, become slightly acid.

Table XVI presents the results of a comparison between the results produced by the addition of these three salts to different soil extracts.

TABLE XVI.—*Comparison of the effects of potassium nitrate, sulphate, and chloride upon oxidation in various soil extracts.*

No.	Culture.	Percentage increase due to KNO_3.	Percentage increase due to KCl.	Percentage increase due to K_2SO_4.
1	Penn clay	33	29	17
2	Arlington clay loam	45	27	....
3	Lyons silt loam (average of two experiments)	16	22	43
	Average	31	26	30

From the results here presented it appears that potassium chloride and sulphate, although producing slightly acid conditions, are not materially less efficient in promoting the oxidizing power of plants in soil extracts than potassium nitrate when added to the same extracts. Moreover, these results are in harmony with those already given in connection with the comparison of potassium nitrate with other nitrates where it was also shown that the potassium had this same retarding effect upon oxidation.

As a final test an experiment was made in which potassium was furnished in the form of the hydroxide. At the dilution in which it was used N/1000 potassium hydroxide exerts no harmful action upon wheat plants. A solution of N/1000 sodium hydroxide was used in other cultures for comparison. The results of this experiment are shown in Table XVII.

TABLE XVII.—*Relative growth and oxidation resulting from the addition of potassium and sodium hydroxides to extract of Hagerstown loam. Growth expressed in terms of relative green weight.*

[P. p. m.=parts per million.]

No.	Culture.	Relative growth.	Relative oxidation.
1	Extract Hagerstown loam	100	100
2	Same+N/1000 KOH (39 p. p. m. K)	181	83
3	Same+N/1000 NaOH (23 p. p. m. Na)	165	112

The potassium hydroxide produced a large increase in growth in this experiment, but, as was the case with other potassium compounds, caused a small amount of oxidation. Sodium hydrate, though less beneficial to growth, is much more beneficial to oxidation.

It seems to be logical to conclude from these different experiments that the action of potassium is not highly conducive to oxidation in the majority of instances. This property appears to be quite independent of the salt which is used.

Many of the soils at our disposal were found to give material responses to the application of phosphates, both to the soil itself and to aqueous soil extracts. In most cases the increased growth of plants following the application of phosphates was shown by an improvement both in root and top growth, except in a few cases where the acid monocalcium phosphate was used. There the root growth was very poor, due to the acid condition of the solution.

The effect of three of the different phosphates was first determined by recording the growth and oxidizing power of plants grown in aqueous solutions of the respective phosphate salts. The solutions were made up so that each contained 50 parts per million of PO_4. Plants were installed in the cultures April 18 and grew until April 30. On the last-named day 100 mg. of aloin were added to each bottle and the red colors resulting from oxidation were estimated on the following day. The growth and oxidation relative to the controls in distilled water are shown in Table XVIII, the control being taken as 100.

TABLE XVIII.—*Growth and oxidation resulting from the addition of various phosphates to distilled water. Growth expressed in terms of relative transpiration.*

[P. p. m.=parts per million.]

No.	Culture.	Relative growth.	Relative oxidation.
1	Control in distilled water	100	100
2	50 p. p. m. PO_4 as K_2HPO_4	114	62
3	50 p. p. m. PO_4 as Na_2HPO_4	150	140
4	50 p. p. m. PO_4 as $CaH_4(PO_4)_2$	77	59

The effect of the potassium phosphate, while distinctly beneficial to growth, was not beneficial to oxidation, but actually retarded it, wheras sodium phosphate in an equal amount was distinctly beneficial both to growth and oxidation. This result is in harmony with results given on a previous page, where the effect of sodium salts upon oxidation was shown to be more beneficial than that of the corresponding potassium salts. The acid calcium phosphate, which exerted a depressing effect on growth, also exerted a depressing effect upon oxidation, probably due to its acidity.

Following these observations, experiments were made for the purpose of determining the effect on oxidation produced by adding a phosphate to aqueous extracts of various soils. The salt chosen for this purpose was sodium phosphate, since it was found to act favorably upon growth. The sodium phosphate was added to the soil extracts at the rate of 50 parts of PO_4 per million. Table XIX shows the percentage gain in growth and oxidation in these experiments.

TABLE XIX.—*Percentage increase in growth and oxidation resulting from the addition of sodium phosphate to extracts of various soils. Growth expressed in terms of relative transpiration.*

No.	Culture.	Percentage increase in growth.	Percentage increase in oxidation.
1	Miami black clay loam	22	131
2	Miami silt loam	54	— 33
3	Marshall clay loam	42	36
4	Clarksville silt loam	52	— 23
5	Sassafras silt loam	16	19
6	Elkton silt loam	77	92
7	Hagerstown loam	12	34
8	Dutchess silt loam	1	12
9	Cecil sandy loam	2	88
	Average	31	39.5

The addition of sodium phosphate appears, on the whole, to have been distinctly beneficial to oxidation as well as to growth. In two cases there was a material increase in oxidation, where there was only slight increase in growth, although it is entirely possible that this is due to the fact that these particular results were obtained in cloudy weather in January from experiments continued for only nine days. In a longer period the growth might also have been beneficially affected. In the case of Miami silt loam and Clarksville silt loam, the addition of sodium phosphate to the extracts produced a material increase in growth, but not in oxidation. The reason for this difference seems to be rather obscure, but is most capable of explanation upon the existence of a toxic compound in these soil extracts[a] whose deleterious action upon growth may have been largely overcome by the addition of the sodium phosphate, but still remained inhibitory to oxidation. In all the other cases the addition of sodium phosphate caused material increase in the oxidation accomplished by the plants in the soil extracts as well as in the plant growth. An average of all the results shows that sodium phosphate has a beneficial effect upon oxidation.

While chlorine is not one of the essential constituents of the ash of plants, it occurs in most plants and many agricultural soils are benefited by application of sodium chloride.

Wollny[b] found that the addition of chlorides to the soil diminished the rate of oxidation of organic material. The effect of the addition of potassium chloride to soil extracts was not materially different from the effect of the nitrate or sulphate as shown by Table XVI. The use of potassium chloride may be open to some objections, since potassium has been shown to depress the oxidizing power of roots; consequently sodium chloride was tried in several different soil extracts, as Table XX indicates.

TABLE XX.—*Percentage increase in growth and oxidation in various soil extracts, due to the addition of sodium chloride. Growth expressed in terms of relative transpiration.*

No.	Culture.	Relative growth.	Relative oxidation.
1	Miami black clay loam	22	94
2	Penn clay	19	80
3	Lyons silt loam (average of 3 experiments)	0	12
4	Dunkirk loam	- 1	−29
	Averages	10	39

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[a] A toxic compound has been isolated from this sample of Clarksville silt loam and identified as dihydroxystearic acid. See Schreiner and Shorey, Bul. 53, Bureau of Soils, U. S. Dept. Agr., 1908; Jour. Am. Chem. Soc., **30**, 1599 (1908).

[b] Wollny, Die Zersetzung der organischen Stoffe und die Humusbildungen, Heidelberg, 1897.

The effect of sodium chloride appears, from these experiments, to be distinctly beneficial to the oxidizing power of plant roots and to confirm the results of the experiments in which potassium chloride was used. Although in one instance the sodium chloride decreased the oxidation, the average response for the four soil extracts was well marked and lay in the positive direction.

The action of sulphates upon oxidation has already been shown in Table XVI, where a comparison was made between the nitrate, chloride, and sulphate of potassium, as well as from Table XIV, where the results with potassium sulphate are shown. The effect of sulphate as sodium sulphate was studied in four different soil extracts. The result upon growth and oxidation is shown in Table XXI.

TABLE XXI.—*Percentage increase in growth and oxidation in various soil extracts due to the addition of sodium sulphate. Growth expressed in terms of relative transpiration.*

No.	Culture.	Percentage increase in growth.	Percentage increase in oxidation.
1	Clyde sandy loam	12	23
2	Penn clay	–27	86
3	Lyons silt loam (average of three experiments)	12	11
4	Dunkirk loam	– 1	–47
	Average	– 1	18

From the average result it would appear that sodium sulphate is but slightly beneficial to growth and oxidation, but the average is low on account of the retardation obtained in No. 4. If this result were omitted, the average would be 40, a figure indicating a distinctly beneficial effect on oxidation. In the case of the action of the sodium sulphate the retarding action of the potassium, as in Table XIV, is of course entirely obviated.

In general sodium sulphate has a slightly beneficial effect upon the oxidizing power of plants.

The data presented in the foregoing tables shows that the oxidizing powers of the plants were beneficially affected by the addition of certain salts to the cultures. In most cases where oxidation was increased, plant growth was also increased, but not always, nor indeed, in anything like a strict proportion.

Further consideration of the conditions of experimentation shows that the increased oxidation observed was not due in any considerable degree to the increased growth and oxidation by soil bacteria, since all the soil extracts were filtered through Pasteur-Chamberland tubes, which were frequently heated to a high temperature over a Bunsen flame. The number of soil bacteria in the solution would therefore be small and their action negligible for the purpose of the present discussion.

It seems more logical to conclude that the effect of the salts added was to activate the enzymes which caused the oxidation and thus to produce an acceleration. In view of the important activating effect which certain salts are known to exert upon digestive enzymes in the animal organism, it seems very probable that they play a similar rôle in this case. For example, the presence of calcium chloride accelerates the action of pancreatic juices. Recently it has been shown that salts may exercise a "protective" function for certain enzymes. Thus, Ford and Guthrie[a] found in course of a study of the amylase of resting barley that digestion of barley with sodium chloride, potassium sulphate, potassium dihydrogen phosphate, calcium chloride, calcium sulphate, glycine, asparagine, or alanine results in an increased diastatic activity. The authors hold the view that the enzymes would have little activity were it not for the small amounts of soluble salts in the extract. They found that when barley grains were soaked in water for about forty-eight hours, and then ground and extracted, the enzyme activity was low, owing, not to the solution of enzyme as the result of the first soaking, but to the removal of salts and other substances which help to dissolve and protect the amylase during the extraction of the ground grain.

Extracts containing papain, bromelin, or animal trypsin exhibited greater diastatic activity than extracts containing only the amylase, although such enzymes were proved to be devoid of amylolytic activity in themselves. It was found, however, that boiled solutions of papain gave a marked increase in activity without corresponding solution of nitrogenous material. The authors believe that the results indicate that the amphoteric proteins in the papain prevent the destruction of amylase which would occur under other conditions of extraction.

The length of the roots as a factor in influencing the amount of oxidation is a question which should apparently be considered, since in some cultures the roots attained greater development than in others. A consideration of the actual modus by which oxidation is accomplished, however, makes this question one of minor importance. It has already been shown that when chromogens which upon oxidation yield insoluble dyestuffs are employed, the greatest amount of oxidation is shown to occur on the apical region of the root and that the older portions of the roots accomplished relatively much less oxidation. Since none of the roots, in the time of the experiments, showed any extensive development of branches, it seems logical to conclude that the length of the roots in itself would have a very minor effect upon the amount of oxidation, but that their physiological condition would be of much greater importance.

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[a] Jour. Inst. Brewing, 14, 61 (1908).

EFFECT OF TOXIC COMPOUNDS UPON OXIDATION.

Aside from the foregoing experiments, in which there were used extracts of soils which displayed toxic qualities toward plants, a few investigations were made upon the action of organic compounds whose toxic properties had been previously determined.

The organic compounds employed for this purpose were vanillin, cumarin, and santonin. The compounds were dissolved in distilled water and the resulting solutions used as cultures, taking care that the concentrations chosen were not so great as to be fatal to wheat plants within the duration of the experiment. Vanillin was used at the rate of 100 parts per million, cumarin 10 parts per million, and santonin in a saturated solution, which was nearly 100 parts per million. The growth of the plants as measured by transpiration and stated in figures, taking the growth of similar plants in distilled water as 100 in each case, was vanillin 63, cumarin 81, santonin 75. After the plants had grown in their respective solutions for from twelve to fourteen days, 100 mg. of aloin were added to each and the results noted on the following day. The results agreed in showing no color indications of oxidation in any of the cultures where the toxic compounds were present, although the roots growing in the control cultures in distilled water showed by the red color produced that a material amount of oxidation had been accomplished in them.

That the mere presence of organic materials did not inhibit the oxidation was shown by an experiment employing a solution of leucine which was slightly beneficial to the growth of wheat seedlings in solution cultures. Solutions of leucine containing 50 and 100 parts per million, producing an increase in growth over distilled water of 54 and 98 per cent, respectively, were very favorable to oxidation and produced a much deeper aloin red than the cultures in distilled water.

It can only be concluded, therefore, that the toxic organic compounds studied were deleterious to oxidation because of their toxic properties, and it appears that they were even more deleterious to oxidation than to plant growth.

The oxidizing action of the plants upon toxic organic substances is a phenomenon which has been pointed out by the authors in a previous paper[a] and will be referred to again later. The experiments presented in that paper also showed that the addition of sodium nitrate and calcium carbonate to solutions of toxic organic compounds went far toward decreasing their harmful effects, and in some cases overcame them entirely. That the organic salts and the physiological activities of the plants working together had accomplished the destruction of toxic substances was shown by both plant growth and chemical tests. It now appears that while this destructive action of the toxic body by the plant is going on, the oxidizing power in the presence of an excess, as it were, of toxic body is greatly reduced and may even be entirely inhibited. The conclusion drawn from these experiments was that the plant roots are able to oxidize a certain amount of deleterious organic material and that the presence of salts which favor oxidation increases the ameliorating action of the plant.

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[a] Jour. Am. Chem. Soc., **30**, 85 (1908).

This question was studied a little further by an experiment in which the oxidation in solutions of toxic material was observed. A solution of cumarin containing 10 parts per million, with and without the addition of fertilizer ingredients, was used as a medium for plant growth and subsequently examined for powers of oxidation. Sodium nitrate was added to one portion of the cultures at the rate of 50 parts of NO_3 per million, and calcium carbonate at the rate of 2,000 parts per million was added to another portion of the cultures. Wheat plants were installed in the cultures October 7 and grew until October 17. The oxidation was estimated by means of aloin. Table XXII gives the effect of these treatments upon growth and the oxidation in the toxic solutions and in control solutions to which no cumarin had been added. In each case growth and oxidation of the plants in distilled water are taken as 100.

Table XXII.—*Effect of sodium nitrate and calcium carbonate on growth and oxidation in solutions of cumarin. Growth expressed in terms of relative transpiration.*

[P. p. m. = parts per million.]

No.	Culture.	Relative growth.	Relative oxidation.
1	Distilled water	100	100
2	Same + $NaNO_3$	196	250
3	Same + $CaCO_3$	170	166
4	Cumarin 10 p. p. m	81	31
5	Same + $NaNO_3$	159	139
6	Same + $CaCO_3$	110	131

The results of this experiment show, in harmony with those of the previous work, that the addition of these fertilizer ingredients overcome to a large extent the deleterious effect of the cumarin upon growth, each one making the cumarin solution to which it was added a better medium for growth than distilled water. An inspection of the figures expressing the relative oxidation shows, however, that the addition of these salts produced relatively greater increases in oxidation than in growth. When sodium nitrate was added to cumarin the resulting growth was twice as great as where only cumarin was present; the oxidizing power, however, was increased over fourfold. In comparison with this effect it will be noted that the addition of sodium nitrate to distilled water likewise increased the growth twofold and increased the oxidizing powers two and a half times.. It seems quite evident, therefore, that the ameliorating powers observed under the conditions of the experiment are to be referred to the increased oxidizing powers which are thereby brought about and the consequent diminution in amount and activity of the toxic material.

It may be noted in passing that Le Renard[a] found that nitrates had a greater antitoxic value than other acid radicals when Pencillium was grown in the presence of copper.

THE NATURE AND ACTIVITIES OF THE OXIDIZING ENZYMES.

Mention has been made of the enzymotic nature of the oxidizing action of the roots in preceding pages, and consideration will now be given to the nature of the enzyme or enzymes which bring about the oxidation. So far as known the oxidation effects observed were entirely due to the action of enzymes and not to the other activities connected with the growth of the roots themselves, for it was observed that under certain toxic conditions growth went on while oxidation was inhibited, and similarly, growth was sometimes enhanced by a treatment which did not change the oxidizing powers.

When a few drops of alcoholic guaiac are added to water, or a suitable solution of salts, in which wheat seedlings have grown for several days, there is sometimes a faint blue color indicating the presence of oxidase, but more often there is no blue color. When a drop of hydrogen peroxide is added, however, the liquid turns blue, giving a color varying from medium to very intense, depending somewhat upon the age of the seedlings, and the number of roots which have grown in the culture. The guaiac-peroxide reaction indicating a peroxidase is confirmed by phenolphthalin and aloin, both of which agree in showing the presence of peroxidase. When the roots of a young wheat plant are immersed in an alcoholic guaiac solution, they immediately turn blue, indicating that they are relatively rich in oxidase, although but little oxidase appears in the water in which they grew. This may be due to the retention of oxidase by the root cells during life, but when the outer cells are killed by the alcoholic guaiac the oxidase escapes and becomes evident through its reaction with guaiac. An aqueous extract of crushed roots shows strong oxidase reaction as well as peroxidase reaction. In the course of an examination of different parts of the young wheat plants, it was found that the partially depleted seeds showed a very strong oxidase reaction when guaiac was used, while the peroxidase reaction was relatively less than in the extract of crushed roots.

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[a] Essai sur la valeur antitoxique de l'aliment complet et incomplet. Paris (1907).

When the solution in which wheat roots have been grown for some days is boiled for five to ten minutes and cooled the oxidase and peroxidase reactions disappear.

The temperature at which the peroxidase is destroyed as a result of applying heat was determined by heating a culture liquid which showed an active peroxidase action. The culture liquid was heated to successively high temperatures and held at each for five-minute periods. The temperature at which the enzymes appeared to be destroyed was 60° C., or very close thereto.

The culture liquid was examined for enzymes in a series of cultures of different ages to learn whether the enzyme reaction was equally strong in all. Wheat seeds were germinated on perforated cork plates floating on the surface of water in crystallizing dishes of 500 c. c. capacity. When cultures were on hand aged 2, 3, 4, 5, 6, and 7 days, respectively, tests were made with guaiac, alcoholic aloin, and phenolphthalin.

The tests with guaiac showed that the oxidase reaction which was weak in the 2 and 3 days' cultures was quite strong at 4 days. The tests with alcoholic aloin and phenolphthalin showed that the peroxidase reaction was strongest in the 6 and 4 day cultures, and considerably weaker in each of the others.

Certain phenomena observed in connection with the use of aloin in aqueous and alcoholic solutions suggested that they react differently with oxidases and peroxidases. Experiments were accordingly installed to test specifically the action of each solution. Two solutions of aloin were prepared: I contained 0.250 gram of aloin in 50 c. c. of water; II contained 0.250 gram of aloin in 50 c. c. of 95 per cent alcohol. One cubic centimeter of aloin solution, I or II, was added to 5 c. c. of liquid in test tubes according to the plan shown in Table XXIII. The tubes were prepared and aloin added at 2.45 p. m., on January 10, and the observations recorded in the third column of the table were made at 11 a. m., on January 11. The culture liquid when added to the tubes showed no oxidase but good peroxidase reaction with guaiac.

TABLE XXIII.—*Comparative reaction of aqueous and alcoholic solutions of aloin to a liquid containing peroxidase.*

Nos.	Solution.	Color observed at end of 20¼ hours.
1 and 2	Unboiled liquid + 1 c. c. aqueous aloin	Pink.
3 and 4	Boiled liquid + 1 c. c. aqueous aloin	Do.
5 and 6	Distilled water + 1 c. c. aqueous aloin	Faint pink.
7 and 8	Unboiled liquid + 1 c. c. alcoholic aloin	Deep pink.
9 and 10	Boiled liquid + 1 c. c. alcoholic aloin	Yellow.
11 and 12	Distilled water + 1 c. c. alcoholic aloin	Do.

An inspection of these results shows that when only peroxidase is present aqueous aloin is not particularly applicable for demonstrating the presence of that enzyme, in the absence of growing plants, since there was the same development of pink color in boiled as in unboiled liquid. Alcoholic aloin, on the contrary, was changed to a deep pink in the unboiled liquid, but remained unchanged alike in the boiled liquid and in the distilled water.

The action of the different aloin solutions was next tested in liquids which also possessed a strong oxidase reaction. The roots of 10 wheat seedlings 12 days old were removed and crushed in a mortar with distilled water. The filtered liquid obtained from this source gave a strong reaction for oxidase when tested with guaiac. As before, 1 c. c. of aloin solution, I and II, was added to 5 c. c. of the root extract in test tubes, according to the plan shown in Table XXIV. The tubes were prepared and aloin added at 4.30 p. m., on January 13, and the observations recorded in the third column of the table were made at 11 a. m. on the following day.

TABLE XXIV.—*Comparative reaction of aqueous and alcoholic solutions of aloin to a liquid containing oxidase.*

No.	Solution.	Color observed 11 a. m. Jan. 11.
1, 2, 3	Root extract+1 c. c. aqueous aloin	Red.
4, 5	Distilled water+1 c. c. aqueous aloin	Faint pink.
6, 7, 8	Root extaact+1 c. c. alcoholic aloin	Pronounced pink.
9, 10	Distilled water+1 c. c. alcoholic aloin	Faint pink.

The results of these experiments supplement those of the foregoing, in which a peroxidase liquid was used, by demonstrating that the oxidase caused a much greater conversion of aloin to " aloin red " with the aqueous than with the alcoholic solutions of aloin. There was in the root extract a distinct peroxidase reaction to guaiac in addition to the oxidase reaction, and it is only natural that in tubes 6, 7, and 8 there should be some development of color when alcoholic aloin was added.

It is evident, from the above results, that in the absence of living plant roots aqueous aloin is principally a reagent for oxidase and alcoholic aloin for peroxidase. In the experiments where plants are employed it is however needless to say that only aqueous solutions of aloin can be used. But there again the living roots may introduce factors which cause peroxidase reaction with aqueous aloin.

Aloin and phenolphthalin, having shown their usefulness as indicators of enzyme action, several other substances were investigated for comparison. Leuco-rosolic acid was prepared by reducing rosolic acid with zinc dust in alkaline solution. When reduction was practically complete the solution was filtered and neutralized with hydrochloric acid, then rendered slightly alkaline with sodium hydroxide. One cubic centimeter of this solution was added to three different liquids; (I) liquid from culture 6 days old; (II) the same liquid after having been boiled ten minutes; (III) distilled water. When examined twenty-four hours later I was pronounced rose-red, while II and III were merely faint pink, which indicates that leucorosolic acid is capable of showing the action of these oxidizing enzymes.

Attempts were made to use ferrous ammonium sulphate and potassium iodide as indicators of the oxidizing powers of plants by putting small amounts into cultures containing living plants. Ferrous ammonium sulphate was, in the space of time of the experiment, oxidized by mere contact with the atmospheric oxygen, and was therefore discarded as an indicator. Potassium iodide was not oxidized to free iodine, as Raciborski[a] has also found.

EFFECT OF DIFFERENT CONDITIONS IN THE SOLUTIONS UPON THE ACTIVITY OF THE ENZYMES.

Mention has previously been made of instances where the variation in oxidation appeared to be partly due to the acidity or alkalinity of the solution used as a culture liquid. In such cases the growth of the plant roots was affected when the conditions of alkalinity or acidity were very great. The effect is the more harmful when young seedlings are put into such solutions, because at the beginning of the experiment, when the plants are very tender, the acidity or alkalinity is greatest and gradually diminishes during the progress of the experiment. In investigating the effect of acid or alkaline conditions in the culture media, instead of using either alkaline or acid solutions at the start, a method was used whereby the originally neutral solutions became acid or alkaline as a result of the selective absorption of the plant in withdrawing nutrients from the solution.[b] It has been demonstrated by Kohn and Czapek[c] that fungi may render their culture media alkaline or acid as a result of their selective absorption, whereby an acid or a basic radical is removed more rapidly than the radical to which it is linked. Reed[d] has observed a similar action for the higher plants and pointed out its bearing upon the composition of nutrient solutions.

Solutions were made up from salts whose radicals are differently absorbed by growing plants, e. g., calcium nitrate and potassium sulphate. Where calcium nitrate is furnished, the plant takes up NO_3

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[a] Bul. Acad. Sci., Cracovie, 668. 1905.

[b] See Cameron, Rept. 71, U. S. Dept. Agr., 1902, p. 67; Buls. 30 and 41, Bureau of Soils, U. S. Dept. Agr., 1905.

[c] Beitr. Chem. Phys. u. Path., 8, 302 (1906).

[d] Ann. of Bot., 21, 501 (1907).

more rapidly than Ca, with the result that the solution becomes increasingly alkaline. In the case of potassium sulphate, the plants take up K more rapidly than SO_4, with the result that the solution becomes acid. In the experiments which were made upon this problem an attempt was made to determine the acidity or alkalinity of the solutions when the experiment was terminated. A measured quantity of solution was boiled in a platinum vessel to drive off CO_2 and then titrated. The results of these determinations are shown with the other results in Table XXV.

TABLE XXV.—*Oxidation and growth of wheat plants in solutions which became acid or alkaline as the result of plant growth. Relative growth measured by transpiration.*

[P. p. m.=parts per million.]

No.	Culture.	Relative growth.	Acidity.	Alkalinity.	Relative oxidation.
1	Control in distilled water	100			100
2	30 p. p. m. Ca as $Ca(NO_3)_2$	174		N/5000	401
3	30 p. p. m. Ca as $CaCl_2$	112		N/7500	107
4	30 p. p. m. Ca as $CaCO_3$	123		N/7500	175
5	66 p. p. m. SO_4 as $(NH_4)_2SO_4$	46	N/7500		102
6	66 p. p. m. SO_4 as K_2SO_4	78	N/10000		100
7	100 p. p. m. NO_3 as $NaNO_3$	201		N/5000	401
8	35 p. p. m. K as KCl	92	Neutral.	Neutral.	97
9	100 p. p. m. NO_3 as $NaNO_3$ (N/620) 63 p. p. m. K as KCl (N/620)	288		N/10000	688
10	100 p. p. m. NO_3 } as KNO_3 (N/620) 63 p. p. m. K } 63 p. p. m. K as K_2HPO_4 (N/620)	295		N/20000	250

These results show that six of the nine solutions became alkaline, two became acid, and one remained neutral. Growth and oxidation were less in the acid solutions than in those which became alkaline, although in the case of calcium chloride the result was quite low. In the case of potassium sulphate and potassium chloride a part of the depression may be due to the effect of the potassium, which usually fails to increase, materially, oxidation, but such is not the case with ammonium sulphate. Neither is it probable that the sulphate radical is the depressing factor, since calcium sulphate compares favorably with calcium nitrate in its effect upon oxidation, as was shown in Table XIII. The more favorable effect of No. 2 in Table XXV upon oxidation over Nos. 3 and 4 is probably to be attributed to the presence of nitrate, which likewise appears to be responsible for a material increase in growth. The greater oxidation accomplished by No. 9 over No. 10 is probably not to be attributed to the presence of Cl, but to the smaller amount of K present in No. 9.

On the whole, it appears that the oxidation is affected to a certain extent by conditions of acidity or alkalinity arising in the culture medium, but oxidation seems to be more materially affected by the specific action of the salts and their elements in the solution.

The effect of acid and alkaline conditions upon the activity of peroxidase was investigated by the following experiment in which alcoholic aloin was used as the indicator. A liquid showing strong peroxidase action was taken from a pan in which several hundred seven-day-old wheat seedlings were growing. Various amounts of N/50 HCl and N/50 NaOH were added to a set of tubes, each containing 10 c. c. of the culture liquid and 1 c. c. of alcoholic aloin solution, added at 3 p. m., January 13. Table XXVI shows the amount of acid or alkali added in each tube, and gives the record of the colors observed at 11 a. m. the following day.

TABLE XXVI.—*Effect of acid and alkaline conditions upon the activity of peroxidase in the absence of plants.*

No.	Culture.	Color observed at end of 20 hours.
1	10 c. c. culture liquid +0.1 c. c. N/50 HCl	Faint pink.
2	Same +0.2 c. c. N/50 HCl	Do.
3	Same +0.5 c. c. N/50 HCl	No change.
4	Same +0.7 c. c. N/50 HCl	Do.
5	Same +1.0 c. c. N/50 HCl	Do.
6	Same +0.1 c. c. N/50 NaOH	Red.
7	Same +0.2 c. c. N/50 NaOH	Wine red.
8	Same +0.5 c. c. N/50 NaOH	Deep wine red.
9	Same +0.7 c. c. N/50 NaOH	Do.
10	Same +1.0 c. c. N/50 NaOH	Do.
11	Same neutral to litmus solution	Deep pink.
12	Same neutral to litmus solution	Do.

From these results it can only be concluded that a slightly alkaline medium is most favorable for this peroxidase reaction. It will be remembered that Wollny[a] found also that the oxidation processes in the soil were distinctly favored by slightly alkaline conditions.

The effect of putrefactive processes upon oxidation is another question which was briefly investigated. It has been observed that when a number of seedlings were placed without any support into water (the entire root system, seed and lower part of the plant being thus submerged) which contained aloin, the red color first produced subsequently disappeared. An experiment was accordingly planned to learn whether oxidation phenomena would be affected when the seeds were submerged and gave rise to products of putrefaction. Twelve cultures of wheat plants were prepared and allowed to grow four days in tap water. In one-third of the cultures the seedlings were adjusted in the notched corks so that only the root systems of the plants were submerged; in one-third of the cultures the seedlings were lowered so that the seeds were also submerged, and one-third had the seedlings entirely submerged. On the fourth day 100 mg. of aloin were added to each culture jar, and they were examined twenty-four hours later with reference to the production of colors. It was found that the cultures planted with only the root systems submerged showed a very considerable amount of oxidation, but in those where the seeds or entire plants were submerged there was none of the red color produced by oxidation. In these cultures where no oxidation was shown there were putrefactive processes at work, a fact which is taken to mean that the oxidation effects are not observed when putrefaction processes occur. Whether this inhibition of oxidation is due to putrefactive processes or to a perverted metabolism of the plant which is functioning under somewhat anaerobic conditions remains undecided.

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[a] Die Zersetzung der organischen Stoffe und die Humusbildungen, Heidelberg, 1897.

That the oxidizing power of the plant was not destroyed is shown by the fact that by raising the seeds out of the culture water and refilling the jars with fresh tap water containing aloin, the characteristic oxidation occurred.

The foregoing experiments raised a question as to the amount of oxidation which occurs in poorly drained soils where anaerobic and putrefactive processes are known to exist. In investigating this question, two crops of wheat seedlings were grown in Arlington clay loam in paraffined wire pots, giving the pots different amounts of water.

Lot I of the pots was taken at the optimum water content of the soil. The soil in lot II was kept saturated with water from the start and the soil in lot III was saturated after the wheat seedlings were up. The relative green weight of the first crop of wheat plants, which grew from February 18 to March 14, was: I, 100; II, 111; III, 104. The relative weight of the second crop, grown from March 17 to April 8, was: I, 100; II, 67; III, 116. Extracts of these soils were made and wheat plants were grown eleven days in the various extracts. At the end of that time the growth and oxidizing power of the plants in the different solutions were determined, with the result shown in Table XXVII.

Table XXVII.—*Growth and oxidation in extracts of soil of varying moisture content. Growth expressed in terms of relative transpiration.*

No.	Culture.	Relative growth.	Relative oxidation.
1	Soil kept at optimum	100	100
2	Soil kept at saturation	78	69
3	Soils saturated after plants were up	151	11

These results show that the effects of the poor drainage conditions appear to be much more marked upon oxidation than upon growth. The soil which was kept at optimum and only saturated after the plants had started seemed to remain favorable to growth in the pots and in the extracts, but its extract was plainly not favorable to oxidation. In regard to the increase of growth, it should be remembered that this lot of soil was alternately very wet and dry during the course of the experiment.

SUMMARY.

(1) Roots of growing plants exhibit an extracellular oxidizing power which may be demonstrated by the use of suitable chromogens in nutrient solutions or soil extracts.

(2) The oxidizing power appears to be most energetic in the region of the root where root hairs are found, and to decrease gradually in activity as that portion of the root becomes older.

(3) The oxidizing power of plants grown in extracts of productive soils is greater than that of plants grown in extracts of unproductive soils.

(4) Treating the soil extracts with an absorbing agent is usually beneficial to oxidation.

(5) The distillate of a poor soil extract which contains volatile toxic compounds was less favorable to oxidation than the residue remaining from distillation.

(6) The process of oxidation is usually accelerated by the addition of nitrates to an aqueous soil extract. The addition of ammonium sulphate is less beneficial to oxidation than the addition of an equal amount of nitrogen in the form of nitrate.

(7) Calcium salts were found to increase the amount of oxidation in cultures to which they were added.

(8) The addition of potassium salts was not generally beneficial to the processes of oxidation. In some cases their presence caused a material retardation of the oxidation. The most of the retardation was due to the action of the potassium itself and not to the formation of acid conditions in the solution. Sodium or ammonium salts of the same acid were more favorable to oxidation than the corresponding potassium salt.

(9) Phosphates usually produced material increases in the oxidation in solutions to which they were added.

(10) Chlorides and sulphates, when combined with a suitable base, like sodium, are somewhat beneficial to oxidation, but are not as favorable as the corresponding nitrate would be.

(11) The presence of toxic organic substances in solution was extremely deleterious to the oxidizing power of the plants. The oxidizing power of the plants, especially in the presence of nitrates, was able to alleviate the toxicity of such solutions.

(12) The process of oxidation by roots is largely, if not entirely, due to the activity of a peroxidase produced by the roots. This oxidizing enzyme is most active in neutral or slightly alkaline solutions. The activity of the enzyme may be inhibited by the presence of acid and also by the conditions in solutions where putrefaction processes occur.

(13) This oxidation by roots has considerable agricultural interest, since processes promoting oxidation play a large part in the best methods of soil cultivation and tillage.

○

Issued October 8, 1909.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS—BULLETIN No. 57.
MILTON WHITNEY, Chief.

A STUDY OF CROP YIELDS AND SOIL COMPOSITION IN RELATION TO SOIL PRODUCTIVITY.

BY

MILTON WHITNEY.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1909.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., February 8, 1909.

Sir: I have the honor to transmit herewith a manuscript of an article entitled "A Study of Crop Yields and Soil Composition in Relation to Soil Productivity," and to recommend that this be published as Bulletin No. 57 of the Bureau of Soils.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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A STUDY OF CROP YIELDS AND SOIL COMPOSITION IN RELATION TO SOIL PRODUCTIVITY.

INTRODUCTION.

The maintenance of the productive capacity of soils has been a subject of study and concern from the earliest historic times. The old Roman writers clearly recognized that soils may quickly become worn out by certain methods of cultivation and cropping, and that different types of soils show marked differences in their crop adaptations and endurance under different methods of culture. .

The works of Cato, Varro, Virgil, Columella, Pliny, and Palladius, as well as many of the still earlier Greek writers, show that the proper system of cultivation, manuring, and cropping under intensive methods to maintain the productivity of the soil was uppermost in men's minds at that time. It was clearly apparent to them that system and intelligence, and these alone, were needed to reduce the number of individual failures to maintain the soils generally in a more productive state.

According to Dickson,[a] the Romans had a greater variety of crops and exercised considerably more care in adapting them to the different soils than did the English at the time he wrote (1788), and more than we seem to give in this country. Considering Pliny as more particular in his directions as to the adaptation of crops to soil, Dickson gives Pliny's maxims in detail as follows:

> Such a difference of soil, he says, points out the necessity of describing the kinds proper for the different crops. This is Cato's opinion, that corn should be sowen on land that is stiff, rich, and in good heart; that radish, millet, and panic, should be sowen upon the same kind of land, if moist or wet; that seed should be first sowen in cold and wet soils, and afterwards in warm; that lupines should be sowen in the red soil, the soil called *pulla*, or sandy soil, if they are not wet; *far* in moister fields, where the soil is chalky and red; *triticum* [wheat] in dry land, not liable to weeds, nor in a shade; beans in strong soils; *siligo* and *triticum* in open and exposed fields that receive greatest benefit from the heat of the sun; lentils in uncultivated and red soil, where there is not much grass; barley on fallow, and land so rich as to carry a crop every year. Spring sowing should be used in places that can not conveniently be sowen in autumn, and in soil whose fatness can carry constant crops. This maxim too is exact. These things should be sowen in shallow soil that do not require much sap, as the *cytisus* and *cicer;* legums are excepted, which are pulled

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[a] The Husbandry of the Ancients, Adam Dickson, Edinburgh, 1788, Vol. 1, p. 187.

> up and not cut in reaping; hence they are called *legums*, because thus gathered. In fat soil, should be sown such things as require much food, as garden herbs, *triticum*, siligo, flax. So, for the same reason, the shallow soil is allotted for barley, because it does not require much food, the richer and stiffer for *triticum*. In low lying grounds, *far* rather than *triticum* should be sowen. In grounds neither very high nor low, both *triticum* and barley; hilly ground produces plumper *triticum*, but not so large a crop. *Far* and *siligo* may be appointed to chalky and wet soils.
>
> Theophrastus does not enter into particulars, as the Roman authors do; but he declares, in general, that, to know how to adapt plants to soils is one of the principal things in agriculture.

Regarding the management of soils, Dickson further says:[a]

> By schemes of management, we mean the crops that are cultivated, the culture given them, and the order in which they succeed each other. In Britain we have a variety of schemes of management; we have successions of different crops, and we have the same crops succeeding each other, in different orders. It was so likewise among the Romans; and their different schemes were adapted to their different soils.
>
> When the soil was very good * * * they raised several different sorts of crops in succession. Pliny mentions two schemes in this rich soil: That kind of soil, says he, called tenera may be croped in this manner; barley, millet, raddish, and then barley again, or *triticum*, as in Campania. For one of these crops, the land was always dunged, probably the millet; for Pliny mentions this among the crops to which dung was always applied. In this succession of crops there was no fallow intervening, and Pliny observes, that it was sufficient to plow the land immediately before, or when it was sowen. * * * Another order of croping, says Pliny, after a crop of *far*, let the land rest during the four winter months, and then be sowen with the spring bean, that so it may not rest till next winter, but carry a crop every year. * * * Columella says, that, when beans are sowen upon land that has carried a crop the year immediately preceding, dung must be applied. And Pliny himself says * * * that, even when beans are sown upon land that has not carried a crop, it must have been lately dunged.
>
> Land that was treated in this manner, and carried a crop every year, was not very common; it was found chiefly in Campania, the country which was reckoned the most fertile in Italy. Pliny mentions a very extraordinary field in it, which, as it carried a crop every year, and more valuable crops too than those that have been mentioned, falls naturally to be taken notice of in this place * * *.
>
> Ploughing, as was observed in the last chapter, is the most important operation in agriculture: but it cannot be performed in all its perfection, nor all its advantages obtained, except when land is summer fallowed. Of this the ancients seem to have been very sensible; for, instead of recommending fallowing, as is commonly done by writers on husbandry in modern times, the ancient writers mention it as a necessary preparation for a crop in ordinary soils. In Switzerland, Geneva, and some provinces of France they have a crop and fallow alternately. This seems likewise to have been the common practice among the Romans, from whom these nations no doubt received it. This practice probably arose from the opinion that the earth was in some measure exhausted by carrying a crop, and needed a year's rest to enable it to produce another * * *.

This extract gives a very fair view of the opinions held some two thousand years ago regarding this important matter of soil fertility and of the systems devised to maintain the productivity of soils. It was clearly recognized then, as it still is by many, that the maintenance of productivity is a personal matter with the tiller of the soil and depends upon his knowledge, skill, and industry. The present condition of the agriculture of Italy would seem to bear out this view and give no reason to fear a permanent loss of productivity with efficient methods of soil management, at least in finite time.

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[a] Ibid., pp. 228, 449.

Little progress was made in our knowledge of the soil and its relation to crops or of methods of management until the modern science of agricultural chemistry was established by Liebig about 1840. The mineral theory of plant nutrition supposed that productivity depended upon the amount of available mineral plant-food elements present in the soil. Recently the Bureau of Soils has been able to show that the chemistry of the organic matter of the soil is probably of as much importance in the productivity of land as is the chemistry of the mineral matter. The effects of plowing, fallowing, draining, rotation of crops, and manuring are associated in one way or another with changes in the organic matter of the soil necessary to maintain productivity. In these days, of course, everyone recognizes the importance of cultural operations on physical and biological characteristics of the soil. Such natural agencies as climate, distribution of rainfall, sunshine, etc., are coming to be recognized as at least fully as important as the inherent characteristics of the soil.

The facts established by Liebig concerning the mineral necessities of plant development have been taken too literally and too narrowly as applied to the soil, and permanent losses have been feared which would in time completely exhaust the soil of mineral elements and leave it a barren waste. The impression is very strong in this country to-day that our soils are wearing out at an alarming rate, that yields are falling off, and that, without the liberal and universal use of phosphates, potash salts, and nitrates, to replace the amounts removed by crops, the soils will become permanently sterile.

On the supposition that the soil otherwise remains constant in composition, save only as material may be artificially added to it in fertilizers or subtracted from it by crops sold off the farm, various calculations show that the end of soil productivity under existing methods of culture will come at from seventy-five to one hundred and fifty years.

The fact that the soils of Europe and of Asia have been under agricultural occupation for many centuries, supporting a much denser population than our own, would seem to show such ideas to be erroneous when applied to our own soils, the bulk of which have been occupied for not more than fifty or seventy-five years.

As the researches of the Bureau of Soils have been published in a number of different forms—bulletins, and papers in scientific journals—it will be unnecessary at this place to give a résumé of the functions of the soil and its relation to crop production to explain the apparently anomalous fact that we can extract plant food elements from the soil in our growing crops and yet leave the soil with apparently unimpaired supplies for future crops. Two points, however, will be mentioned to show the futility of the bookkeeping system of estimating the future resources of the soil.

The researches of the several experiment stations throughout the world and the investigations of our engineers on the amount of material carried in solution and in suspension in our principal rivers and borne by the wind, establishes the fact that loss through natural leaching and erosion removes far more mineral plant food elements than do cultivated crops. In cropping soils, therefore, and removing the crop from the land, we remove an inconsiderable amount of mineral material compared with normal losses to which the soil is adjusted through natural laws.

The second point opposed to this bookkeeping system of accounting for the plant-food constituents is that in a small majority of analyses reported in this country and abroad where both soils and subsoils have been examined, the upper soil, from which presumably the roots of annual plants take most of their mineral matter, has a content of potash and phosphoric acid higher than the subsoil.

From the meager information to be found in the works of the early agricultural writers of Greece and Italy it seems probable that the yields per acre obtained at the present time are not much different from those obtained in the earlier historic times. There are not many records in the literature of yields per acre for any field, farm, or country going back for any considerable number of years. Official estimates of yields have been kept by the United States Government and many of the States for the past forty years. Similar statistical estimates have been kept by most of the European countries for the past twenty or thirty years. Beyond this the information is fragmentary and possibly less trustworthy.

In the consideration of data of this kind it would at first sight seem more valuable to have continuous records of successive yields of a single field. However, the yield of a State is probably more reliable in showing changes in productivity because it combines a great number of individual fields and averages the results of all the individual methods used in the community. The first method would have the advantage of actual weight or measure of crop produced on a measured area; this is more certain, but it would depend upon the knowledge and skill of individuals and would vary greatly with the individual and with the soil type. The second method, depending as it does merely on estimates, has a less reliable basis, but largely eliminates differences in individual effort and differences in soil, provided the acreage remains fairly constant. Assuming reliability of the estimates, the second method would undoubtedly give more reliable information concerning the relative productivity of a State. Material changes in acreage or a considerable change of the area of production within the State would of course have an influence which must be considered in comparing and valuing results, even if no figures can be given for an exact expression of such change in the area cultivated.

When the yield per acre for a State or country under practically constant acreage is shown to have increased during a long period of years we may assume that the *productivity* has not declined. Much of this increase may result from improved methods of agriculture, better selection of seeds and crops, or the introduction of more live stock; and, for the purpose of our present inquiry, we need go no further to explain the increase or maintenance of productivity.

There are two matters, however, which should be considered in this connection. The first is the question of commercial fertilizers. If the productivity of the soil of a State depends ultimately and literally upon our returning an equivalent amount of plant-food constituents to the soil to replace that removed by the crop, then the life of the nation will ultimately depend upon the available deposits of nitrates, phosphates, and potash compounds. It is clearly impossible with the available data to give any expression of the amount of such replacement which has been made in the past, but from what we know, so far as the actual importation of mineral material foreign to the farm is concerned, it is negligible.

The use of commercial fertilizers is not old. The potash deposits of Germany were first worked in 1862, the phosphate deposits of South Carolina in 1868. Phosphates were discovered in Florida in 1888 and in Tennessee in 1894. It may be said that the general use of commercial fertilizers began in the United States about the year 1865.

The other matter which should receive attention is the influence of material in the form of foodstuffs imported from less densely settled countries to those of greater population as a possible source of introducing foreign mineral matter to maintain the productivity of the soil of the older and more densely settled countries. If any such transference of mineral material actually takes place to an extent sufficient to maintain or increase the productivity of more densely populated countries, then it is but reasonable to expect that the productivity of the soil of the more recently settled and more sparsely settled countries from which foodstuffs are exported would show a falling off in productivity. From this point of view the soils of the United States might be expected to show some material decline in productivity as a result of the enormous amount of foodstuffs exported, while the soils of Europe, to which these foodstuffs mainly go, should show a corresponding increase. But here again the important thing to determine is whether the productivity of the soils of the newer country is actually declining.

In comparing figures representing yields per acre over a series of years, whether for an individual farm or a State or nation, the one variable factor, the effects of which are difficult to eliminate, is the climate. So great is the influence of climate on the yield of crops that in a period of ten years the difference between the lowest and highest yield is as great or greater than the average. Thus in the decade from 1867 to 1876 the highest yield of corn as reported for Nebraska is 42.2 bushels per acre in 1869, and the lowest yield is 10 bushels in 1874. The difference, 32.2 bushels, is almost the same as the average for the decade, 32.5 bushels. Again in the decade from 1887 to 1896 the highest yield was 37.5 bushels in 1896, and the lowest 6 bushels in 1894. The difference, 31.5 bushels, is greater than the average for the decade, which is given as 26.2 bushels. There was no crop failure reported in the decade 1877 to 1886, in which the lowest yield is 27.4 bushels. In the decade 1897 to 1906 the lowest yield is 14.1 bushels. In the decade 1867 to 1876 occurred the highest and next to the lowest yield for the State in forty years.

The figures representing the yield of corn per acre in Nebraska for forty years, compiled from the published records of the Bureau of Statistics, arranged according to yield in each decade, is given in the following table:

Average yield of corn per acre in Nebraska by years and by decades, 1867–1906.

Year.	Bushels.	Year.	Bushels.	Year.	Bushels.	Year.	Bushels.
1874...	10.0	1881....	27.4	1894....	6.0	1901....	14.1
1868...	22.9	1886....	27.4	1890....	18.0	1898....	21.0
1870...	29.9	1880....	31.0	1895....	16.1	1900....	26.0
1876...	30.0	1882....	34.9	1887....	24.1	1903....	26.0
1873...	35.0	1883....	36.0	1893....	25.2	1899....	28.0
1867...	36.0	1885....	36.7	1892....	28.2	1897....	30.0
1872...	37.8	1884....	37.7	1888....	35.2	1902....	32.3
1875...	40.0	1877....	38.0	1891....	35.2	1904....	32.8
1871...	41.5	1879....	41.0	1889....	36.5	1905....	32.8
1869...	42.2	1878....	42.0	1896....	37.5	1906....	34.1
Decade	32.5	Decade	35.2	Decade	26.2	Decade	27.7

With variations so great as these, and, in fact, with the statistical records of any of the States, it is unwise to draw very positive conclusions from the average yield for decades, as ten years is not a sufficient period to minimize the results of extraordinary seasons.

These variations must be duly considered and carefully weighed in drawing conclusions regarding the increase or decrease of productivity shown by statistical records.

EVIDENCE PRESENTED BY THE YIELD OF CROPS IN EUROPE.

European countries have older agricultural soils than the United States, as they have been settled and have been developing their present agriculture for a thousand years or more, while many parts of our own Western and Central States have seen all of their agricultural development in the past sixty or seventy years.

If the views which have been taught for the past seventy years be correct, that continued cropping gradually exhausts the soil and tends to make it unproductive through loss of mineral plant food, we should expect to find a marked and fundamental difference between the soils of the United States and the older soils of Europe, as shown either in the yield of crops or in the chemical composition of the soils. We will first review such data as are available regarding the yield of crops and then consider the chemical data.

The following is given as the yield per acre of wheat in bushels in several European countries and in the United States for the ten years (1897–1906) in the Yearbook of the Department of Agriculture for 1907, page 620:

Average yield of wheat, of various countries, in bushels per acre.

United Kingdom	32.2
Germany	28.0
France	19.8
Austria	17.8
Hungary	17.6
United States	13.8
Russia (European)	9.2

On the face of it, it is apparent that the older soils of Europe are far from being less productive than the newer soils of the United States. This may be due to a difference in climate, to a greater original productivity of the soil, or to more intensive cultivation and a better system of agriculture than prevails in this country.

From the very meager data which are available, some of which will be given in the following paragraphs, it would appear that the yield of wheat in Germany in the middle of the sixteenth century was about equal to the average for the United States at the present time and that since that time the yields in Germany have about doubled. This should dispose of the idea that there is any material difference in climate or in original productivity of the soil, and throw us back to the personal effort of the farmer and the development of a more efficient system of agriculture.

The French minister of agriculture[a] gives the average yield per acre of the principal cereal crops in France from 1815 to 1876, which, reduced to bushels per acre and ten-year averages, is as follows:

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[a] Bul. Min. Agr. Comm. France. Récoltes des Céréales et des Pommes de Terre de 1815 à 1876, pp. 456–459 (1878).

Yield of cereals in France, 1815–1876, by decades.

[Reduced to bushels[a] per acre.]

Year.	Wheat.	Rye.	Barley.	Oats.
1815-1824	12.41	10.58	14.87	17.50
1825-1834	14.05	12.89	15.30	18.52
1835-1844	14.90	13.59	16.60	20.97
1845-1854	15.78	13.68	18.88	23.66
1855-1864	16.57	14.71	20.78	26.00
1865-1874	16.60	15.30	20.70	25.60
1875-1876	16.24	16.41	19.80	24.63

[a] Bushels of capacity. Statistics for the ten years 1897-1906 indicate that the average weight of a bushel of wheat in France is 60 pounds, of rye 56.1 pounds, of barley 49.6 pounds, and of oats 36.5 pounds. The statistics for France on pp. 15 and 19 are in bushels of weight customarily employed in the United States (wheat 60 pounds, rye and corn 56 pounds, barley 48 pounds, oats 32 pounds). The difference is greatest in oats, the average yield of which as given in this table is on a basis some 14 per cent lower than in the tables on pp. 15 and 19, covering later years. Comparisons between these tables should not be made without making allowance for this.

The yield of wheat has increased from 12.41 to 16.60 bushels; of rye, from 10.58 to 16.41; of barley, from 14.87 to 20.78; and of oats, from 17.50 to 26.00. The great increase in the yield of cereal crops for France occurred prior to 1860.

Quite recently the Bureau of Statistics of this department has published a report on the cereal production of Europe[a] for the past twenty years or so.

The following table summarizes the yield per acre in five-year periods, the full data for each country being given further on:

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[a] Cereal production of Europe, by Frank R. Rutter. Bul. 68, Bureau of Statistics, 1908.

Average annual yield of grain, by countries and by five-year periods.

Country.	Wheat.				Rye.				Barley.				Oats.				Corn.			
	1886–1890.	1891–1895.	1896–1900.	1901–1905.	1886–1890.	1891–1895.	1896–1900.	1901–1905.	1886–1890.	1891–1895.	1896–1900.	1901–1905.	1886–1890.	1891–1895.	1896–1900.	1901–1905.	1886–1890.	1891–1895.	1896–1900.	1901–1905.
Austria-Hungary:	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*
Austria	15.9	16.1	16.3	18.5	15.8	15.7	15.9	18.6	20.1	21.3	20.8	23.7	24.3	25.1	25.5	26.7	19.5	19.9	18.9	18.5
Hungary	17.6	19.1	16.7	17.9	15.6	16.9	16.3	17.6	17.9	21.8	22.1	22.5	20.6	25.7	30.1	30.1	18.5	23.2	22.6	19.3
Winter	17.9	19.3	16.8	18.0	15.7	17.0	16.4	17.7	18.2	20.9	20.9	22.3	......	......	......	......	......	......	......	......
Spring	12.6	14.8	13.0	13.2	13.0	14.9	13.8	13.6	17.9	21.9	22.2	22.5	......	......	......	......	......	......	......	......
Belgium:																				
Winter	27.1	27.8	29.7	34.0	25.4	28.9	30.1	34.0	40.8	40.4	43.6	52.0	49.8	50.0	56.8	64.7	......	......	......	......
Spring	21.8	24.5	*a* 22.7						33.6	33.7	35.8	41.0								
Denmark	35.8	38.7	41.0	40.2	24.6	26.7	25.8	26.8	29.7	30.4	30.9	34.0	32.0	33.8	35.5	35.9	......	......	......	......
France	17.8	17.7	19.3	20.2	16.4	17.9	17.1	16.8	21.9	21.5	22.5	24.0	30.2	28.7	30.1	32.0	19.3	19.1	19.0	19.4
Germany	20.3	23.3	27.0	28.2	16.0	19.9	23.0	24.9	24.0	28.9	*l* 30.7	......	33.2	37.7	45.0	47.1	......	......	......	......
Winter	21.4	23.5	27.3	28.1	16.1	20.0	23.2	25.1	29.0	33.8	*l* 37.8	......								
Spring	17.8	21.3	*a* 23.3	28.0	12.1	15.7	16.8	17.5	23.9	28.8	31.8	34.3								
Italy	*b* 12.1	11.2	*c* 12.8	13.1	*b* 12.7	12.3	......	......	*b* 13.4	10.8	*c* 13.2	......	*b* 17.0	16.2	......	......	*b* 15.9	15.1	*c* 16.5	20.2
Netherlands	28.1	27.2	29.8	32.5	22.6	23.4	24.9	25.8	42.4	43.1	45.2	48.0	45.9	46.1	50.8	53.9	......	......	......	......
Winter	......	*d* 28.0	29.8	32.4	......	*d* 24.7	24.9	25.9	46.4	47.5	48.0	50.7								
Spring	......	*d* 28.3	30.0	35.3	......	*d* 20.8	20.3	22.8	34.7	35.7	38.1	40.8								
Norway	24.3	27.9	26.7	*e* 22.2	27.9	27.8	27.7	25.8	33.0	33.0	34.5	28.9	40.6	44.4	41.0	33.9	......	......	......	......
Roumania	15.3	16.2	13.1	18.3	13.8	16.1	13.4	18.7	13.3	17.0	13.7	18.5	18.0	18.5	16.0	23.0	14.4	14.6	14.6	13.3
Russia (total)	......	*f* 10.3	8.7	10.3	......	*f* 12.0	11.2	11.7	......	*f* 14.4	12.4	14.2	......	*f* 20.8	18.9	20.0	......	*f* 11.8	13.5	13.7
Winter	......	*f* 12.9	10.6	13.9	......	*f* 12.1	11.3	11.8												
Spring	......	*f* 9.2	8.0	9.0	......	*f* 10.2	9.4	9.5												
Russia, European	*g* 7.9	8.9	8.4	10.3	*g* 9.5	10.3	11.3	*h* 12.2	*g* 11.0	13.7	12.3	14.2	*g* 15.1	17.7	18.6	20.0	......	*m* 13.9	13.5	13.6
Winter	*g* 11.1	11.2	10.6	13.9	*b* 9.4	10.4	11.3	11.8												
Spring	*g* 6.8	7.9	7.5	8.8	*b* 4.8	8.0	8.2	8.9												
Servia	......	*i* 11.1	*j* 13.9	12.6	......	*i* 8.9	*j* 13.5	9.9	......	*i* 11.1	*j* 16.4	13.9	......	*i* 12.5	*j* 24.9	14.7	......	*i* 13.8	*j* 22.2	13.4
Winter	......	*i* 11.4	*k* 15.2	*h* 12.8	......	*i* 9.8	*k* 14.6	*h* 11.2												
Spring	......	*i* 8.4	*k* 10.8	*h* 7.9	......	*i* 6.8	*k* 13.1	*h* 8.2												
Spain	*b* 8.8	*d* 11.6	10.8	13.0	*b* 10.5	*g* 11.6	10.9	12.6	*b* 10.1	*f* 20.4	16.1	18.9	......	*f* 15.3	18.0	20.5	*b* 24.3	*f* 21.4	19.1	22.5
Sweden	*b* 23.2	23.5	26.1	25,0	*b* 22.4	21.5	21.9	22.2	*b* 27.0	25.0	25.2	24.6	*b* 32.0	29.8	28.1	27.7	......	......	......	......
Winter	*b* 23.4	23.7	26.5	25.3	*b* 22.5	21.6	22.0	22.3												
Spring	*b* 20.6	21.3	21.2	22.0	*b* 16.3	17.2	16.7	17.5												
United Kingdom	30.4	29.0	32.8	31.7	......	......	......	......	33.9	34.2	35.0	34.3	41.8	43.5	43.4	44.7	......	......	......	......
Great Britain	30.4	29.0	32.7	31.7	......	......	......	......	33.7	33.8	34.6	33.6	39.3	39.6	39.8	40.5	......	......	......	......
Ireland	27.9	30.7	32.0	34.6	24.1	26.2	24.8	27.1	36.4	39.7	40.2	42.2	47.6	53.3	53.0	56.7	......	......	......	......

a Average, 1896–1899. *b* 1890. *c* 1896. *d* Average, 1892–1895. *e* Average, 1902–1905 *f* Average, 1894–1895. Average, 1888–1890. *h* Average, 1901–1904. *i* 1893. *j* Average, 1897–1900. *k* Average, 1897 and 1900. *l* Average, 1896–1898. *m* Average, 1893–1895.

Commenting on this data, Doctor Rutter has the following to say:

AVERAGE YIELD OF GRAIN.

Wheat.—On comparing the area under wheat in northwestern Europe in 1905 with the average crop during 1901–1905, it appears that the average yield per acre exceeds 25 bushels; in southwestern Europe the average yield is only 16 bushels per acre, and in eastern Europe but 12 bushels. For Europe as a whole the average yield is slightly under 14 bushels per acre.

It appears, therefore, that the average yield per acre is highest where wheat culture is least generally practiced and where the acreage under grain shows the smallest increase. In other words, the extension of the wheat area is most marked where the average yield per acre is lowest.

This condition holds true as regards individual countries as well as the larger divisions of Europe. The United Kingdom, Belgium, the Netherlands, and Denmark are at the same time the four countries in which the wheat acreage during the last twenty years has shown the largest reduction and the four countries which show the largest yield per acre. In each of these countries the acreage under wheat has fallen at least one-fifth in amount, while in each of them over 30 bushels per acre has been harvested on an average during the last five years.

At the other end of the series stands European Russia, in which the increase in acreage during the twenty years was no less than 60 per cent, while the average yield per acre was little more than 10 bushels.

Between these two extremes the relation pointed out between yield and acreage has been by no means so constant, but the divergence is not sufficiently marked to affect the general correspondence. In Sweden, for instance, the acreage under wheat has shown a considerable increase, while the average yield per acre is high, nearly 25 bushels per acre. On the other hand, in Spain the low average yield, 13 bushels per acre, has been accompanied by a small increase in the acreage and the crop.

That the extent of wheat culture should vary inversely as the average yield per acre, or, in other words, that where the results are best the smallest areas are devoted to wheat, seems at first sight paradoxical. It must be remembered that a high average yield, such as shown in the Teutonic countries of Europe, presupposes intelligence on the part of the farmers and valuable land justifying a large outlay of labor and capital. These conditions are much more favorable to the growth of crops requiring intensive cultivation than to grain crops, which give the highest profit when grown on new land on a large scale. Low average yields, if obtained at a low cost of production, produce a greater aggregate profit than can be obtained from grain crops on the smaller tracts in northwestern Europe, where the high price of land necessitates its use in intensive culture. The foregoing table contains unweighted averages of the yearly average yields shown later in the detailed tables.

Rye.—The yield of rye is highest in Belgium, where during the five years 1901–1905 an average of 34 bushels per acre was obtained. After Belgium come Ireland, Denmark, the Netherlands, Norway, and Germany, in all of which an average yield of from 25 to 27 bushels per acre was obtained. The lowest average yield per acre during the same years was obtained in Servia, 10 bushels per acre, while in European Russia the average yield was slightly more than 10 bushels and in Spain 13 bushels per acre.

Barley.—Of barley, as of rye, the highest average yield per acre during the last five years was obtained in Belgium, in which more than 50 bushels per acre was grown on an average, while the average yield of winter barley alone was 52 bushels per acre. In the Netherlands the average yield was only slightly lower, amounting to 51 bushels per acre for winter barley and 48 bushels for barley of both kinds. Outside of these two countries barley is grown principally as a spring crop; and if that variety alone be considered, Ireland, with 42 bushels per acre, shows the highest average yield. In Germany, Denmark, and Great Britain the average yield per acre is 34 bushels. The lowest average yields per acre recorded are shown by the statistics of European Russia and Servia, according to which but 14 bushels per acre were raised during each of the five years under review.

Oats.—Belgium records an average yield of oats during the five years 1901–1905 of no less than 65 bushels per acre, while Ireland produced 57 bushels and the Netherlands 54 bushels. The smallest average yield per acre recorded is that of Servia, where only 15 bushels were obtained, and European Russia with 20 bushels.

Corn.—The variations in the average yield per acre of corn are far less marked than the variations in the grains already considered. The almost total absence of its culture from any country included in the northwestern division eliminates the very countries where intensive culture is practiced. The highest yield recorded in 1901–1905 was 22½ bushels per acre in Spain, while the lowest, between 13 and 14 bushels, was obtained in Roumania, Servia, and European Russia.

Considering the average yield of grain in five-year periods in the above table and the yearly yields from which this is made up, as given in the accompanying tables, and bearing in mind what has been said regarding the great fluctuations due to seasonal variations in climate, it may safely be said that the figures give no evidence of decreased productivity of the older soils of Europe in the past twenty-five years. From the more meager information which we have concerning production during earlier periods and the opinions of European writers who have especially investigated this subject from actual farm records, it would seem that there has been a decided tendency toward increased production; and this has resulted mainly from better methods of soil management, as the use of commercial fertilizers is modern in Europe as it is in this country.

Acreage and yields of cereals in Austria, 1884–1906, by years.

Year.	Wheat.		Rye.		Oats.		Barley.		Corn.	
	Area.	Average yield.	Area	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.
	Acres.	*Bush.*	*Acres.*	*Bush.*	*Acres.*	*Bush.*	*Acres.*	*Bush.*	*Acres.*	*Bush.*
1884...	2,735,600	15.5	4,896,900	15.1	4,532,900	26.4	2,655,600	19.8	895,300	18.3
1885...	2,950,600	16.0	4,928,400	15.7	4,519,600	22.9	2,882,300	18.4	908,500	22.2
1886...	2,900,800	15,0	4,970,100	14.9	4,616,300	27.3	2,762,600	19.9	895,900	21.5
1887...	2,876,500	18.0	4,969,700	18.0	4,632,600	25.1	2,798,900	21.7	892,000	18.2
1888...	2,930,000	17.4	4,979,200	16.1	4,630,900	25.1	2,795,800	21.5	897,300	18.6
1889...	2,704,400	13.9	4,876,000	14.2	4,639,300	18.9	2,812,800	16.9	943,700	17.8
1890...	2,835,000	15.1	4,941,600	16.0	4,630,100	24.9	2,757,600	20.6	919,000	21.4
1891...	2,747,900	14.4	4,794,800	14.0	4,679,300	25.7	2,815,800	20.2	923,200	21.2
1892...	2,780,400	17.8	4,865,800	17.0	4,628,700	26.9	2,747,000	23.6	907,800	21.8
1893...	2,766,500	15.4	4,800,800	15.9	4,551,600	21.0	2,777,400	19.4	886,400	17.8
1894...	2,713,000	17.4	4,822,000	17.2	4,643,400	26.0	2,806,900	22.3	806,000	17.0
1895...	2,628,600	15.3	4,477,200	14.5	4,817,600	26.1	2,949,500	20.9	859,400	21.9
1896...	2,615,800	16.0	4,537,800	16.3	4,737,500	23.3	2,911,200	19.4	854,600	20.7
1897...	2,615,100	13.2	4,543,600	13.9	4,724,100	21.5	2,899,200	17.6	829,700	18.0
1898...	2,609,300	18.0	4,513,600	17.7	4,697,900	27.4	2,886,000	22.0	841,500	19.5
1899...	2,649,200	19.0	4,549,800	18.7	4,613,800	30.2	2,939,100	24.9	825,200	17.5
1900...	2,632,400	15.5	4,206,000	13.0	4,692,100	25.2	3,049,500	20.2	827,800	18.7
1901...	2,643,400	16.7	4,474,400	16.9	4,622,400	25.6	2,991,900	22.4	820,700	21.4
1902...	2,614,100	19.0	4,527,300	18.2	4,528,000	27.7	3,005,000	24.6	819,200	16.4
1903...	2,600,600	17.8	4,465,600	18.2	4,530,500	28.3	2,977,600	24.8	824,200	19.5
1904...	2,754,900	19.5	4,760,200	19.3	4,501,500	24.3	2,926,300	22.8	836,200	15.0
1905...	2,782,300	19.6	4,864,600	20.2	4,467,600	27.7	2,935,900	24.0	861,100	20.1
1906...	2,880,400	20.2	4,997,200	19.9	4,529,200	34.1	2,909,900	26.1	836,200	20.7

The official records for Austria are continuous from 1884 to 1906, twenty-three years. They show a remarkable uniformity in acreage in wheat, rye, oats, barley, and corn, and no evidence of decrease in productivity in any of these crops.

Acreage and yields of cereals in Hungary, 1883–1906, by years.

Year.	Wheat.		Rye.		Oats.		Barley.		Corn.	
	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.
	Acres.	*Bush.*[a]	*Acres.*	*Bush.*[a]	*Acres.*	*Bush.*[a]	*Acres.*	*Bush.*[a]	*Acres.*	*Bush.*[a]
1883...	6,438,300	14.1	2,714,900	14.8	2,453,000	20.9	2,402,600	16.4	4,507,500	19.4
1884...	6,797,800	15.8	2,729,400	15.7	2,457,800	23.2	2,459,600	19.0	4,585,300	19.7
1885...	7,172,100	16.6	3,061,200	14.7	2,841,600	20.9	2,757,100	20.6	5,396,000	22.3
1886...	7,229,800	15.0	3,048,900	13.4	2,876,400	20.8	2,751,100	14.7	5,502,400	17.7
1887...	7,275,200	20.8	3,035,300	17.9	2,857,400	23.0	2,650,100	21.9	5,291,000	15.9
1888...	7,277,500	19.5	2,992,000	15.1	2,846,300	21.2	2,590,100	18.3	5,398,900	20.1
1889...	7,636,800	12.9	2,931,900	13.5	2,757,000	16.7	2,645,800	13.7	5,585,600	20.5
1890...	7,824,300	19.8	2,942,600	18.1	2,692,600	21.1	2,654,200	20.8	5,589,000	18.4
1891...	7,929,700	18.4	2,798,500	14.1	2,722,300	25.2	2,739,300	20.8	5,830,000	27.7
1892...	8,085,800	18.5	2,973,800	16.5	2,714,700	24.3	2,743,500	19.7	6,031,000	21.9
1893...	8,648,500	19.5	3,269,400	17.9	2,625,400	29.2	2,749,600	24.4	5,941,500	25.8
1894...	8,483,900	18.2	2,991,900	19.5	2,664,600	30.1	2,780,600	22.7	5,898,000	14.0
1895...	8,304,800	20.7	2,802,800	16.7	2,593,600	29.6	2,658,400	21.4	6,208,300	26.5
1896...	8,311,200	19.4	2,807,200	18.2	2,546,700	31.4	2,666,200	24.0	6,049,200	24.7
1897...	7,444,800	11.7	2,691,300	13.5	2,450,400	24.3	2,507,300	17.6	5,793,100	20.5
1898...	8,160,100	17.1	2,735,400	16.9	2,587,300	33.1	2,583,600	23.6	6,191,900	23.9
1899...	8,438,000	17.8	2,816,400	17.7	2,626,900	33.3	2,681,400	24.0	6,169,300	21.2
1900...	8,807,000	17.3	2,752,100	15.4	2,672,700	28.5	2,667,700	21.3	6,396,100	22.9
1901...	8,866,300	15.2	2,795,000	15.6	2,674,300	27.6	2,680,800	19.8	6,392,200	23.1
1902...	8,950,300	20.4	2,803,700	18.7	2,679,400	33.3	2,695,700	24.3	6,287,800	19.1
1903...	9,227,000	19.1	2,801,700	18.1	2,776,500	34.1	2,746,800	24.9	6,579,000	24.2
1904...	9,131,300	16.1	2,760,400	16.6	2,703,700	25.0	2,693,800	19.4	5,828,600	12.1
1905...	9,197,700	18.5	2,790,900	19.0	2,759,300	30.5	2,722,400	24.0	6,235,400	18.0
1906...	9,526,600	21.8	[b]2,802,400	19.4	2,815,700	33.4	2,769,800	26.3	6,731,800	28.0

[a] Prior to 1893, Winchester bushels.
[b] Including maslin in Hungary proper.

The records for Hungary from 1883 to 1906, twenty-four years, show an increasing acreage in wheat and corn of, roughly, 33 and 50 per cent, respectively, and a practically constant acreage in rye, oats, and barley. There is no evidence of decreased productivity of any of these crops, but on the contrary fair evidence of increased productivity.

Acreage and yields of cereals in Belgium, 1880–1905, by years.

Year.	Wheat.			Rye.		Oats.		Barley.		
	Area.	Average yield.		Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	
		Winter.	Spring.						Winter.	Spring.
	Acres.	*Bush.*	*Bush.*	*Acres.*	*Bush.*	*Acres.*	*Bush.*	*Acres.*	*Bush.*	*Bush.*
1880...........	681,800	26.6	23.7	686,100	26.5	616,500	48.6	99,300	36.0	31.4
1881...........	666,000	22.4	19.5	687,000	20.9	616,000	38.7	99,300	35.4	27.9
1882...........	650,000	25.7	19.9	688,000	26.0	616,000	44.5	99,300	38.6	29.1
1883...........	635,000	25.0	22.1	689,000	23.9	616,000	41.1	99,300	37.6	31.1
1884...........	619,000	25.9	22.0	690,000	26.4	616,000	45.4	99,300	42.3	33.8
1885...........	603,000	27.5	22.7	691,000	26.1	616,000	46.4	99,300	42.7	32.1
1886...........	587,000	27.0	22.9	692,000	22.4	616,000	52.4	99,400	39.3	35.8
1887...........	572,000	29.8	....	693,000	27.7	616,000	42.0	99,400	43.9	32.0
1888...........	556,000	21.9	19.3	694,000	21.7	615,000	50.1	99,400	35.1	32.8
1889...........	540,000	28.2	21.8	695,000	26.6	615,000	49.2	99,400	40.4	32.9
1890...........	524,000	28.6	23.2	696,000	28.7	615,000	55.2	99,400	45.4	34.5
1891...........	509,000	23.0	26.0	696,000	22.4	615,000	59.3	99,400	34.3	38.3
1892...........	493,000	31.2	25.9	697,000	33.3	615,000	49.2	99,400	44.9	36.9
1893...........	477,000	27.7	22.7	698,000	28.0	615,000	35.1	99,400	38.8	29.4
1894...........	461,000	28.4	22.5	699,000	30.5	615,000	50.6	99,400	40.6	32.0
1895...........	445,700	28.8	25.5	700,200	30.4	614,500	55.8	99,400	43.6	32.0
1896...........	440,000	30.7	23.7	681,000	32.3	617,000	46.4	99,000	44.6	33.5
1897...........	434,000	26.9	24.0	662,000	29.5	619,000	54.9	98,000	37.3	31.1
1898...........	429,000	31.7	22.8	644,000	29.6	621,000	66.8	97,000	42.2	33.9
1899...........	423,000	26.2	20.4	625,000	26.5	624,000	53.3	96,000	42.3	39.8
1900...........	417,500	33.0		605,800	32.8	625,800	62.6	95,000	50.1	
1901...........	409,700	34.5		620,400	34.1	615,800	65.9	94,600	51.3	
1902...........	415,700	34.9		654,900	34.2	646,200	70.5	93,900	52.9	
1903...........	355,400	34.7		626,800	34.7	705,800	68.5	79,800	49.2	
1904...........	393,200	35.1		639,300	34.4	613,300	61.1	98,800	50.7	
1905...........	402,500	30.8		659,700	32.4	586,500	57.6	94,400	47.9	

The records for Belgium are continuous from 1880 to 1905, twenty-six years, with a decrease of about one-third in the area in wheat, and a nearly constant acreage in rye, oats, and barley, with no indication of decreased productivity for any of these crops.

Acreage and yields of cereals in Denmark, 1883-1905, by years.

Year.	Wheat.		Rye.		Oats.		Barley.	
	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.
	Acres.	*Bush.*[a]	*Acres.*	*Bush.*[a]	*Acres.*	*Bush.*[a]	*Acres.*	*Bush.*[a]
1883	132,900	33.9	670,700	26.4	1,010,500	30.2	769,800	27.1
1884	130,300	36.0	675,400	24.7	1,019,900	30.4	763,100	27.2
1885	127,700	40.1	680,000	26.3	1,027,400	33.1	756,400	27.6
1886	125,100	37.7	684,700	24.2	1,035,800	34.1	749,800	31.0
1887	122,500	43.7	689,300	25.0	1,044,300	30.5	743,100	29.4
1888	119,900	27.4	694,000	23.6	1,052,700	33.7	736,400	30.1
1889	115,600	36.3	697,000	26.0	1,056,900	26.5	730,800	25.5
1890	111,200	33.9	700,100	24.3	1,061,000	35.2	725,100	32.3
1891	106,800	39.1	703,100	27.8	1,065,200	32.3	719,500	31.5
1892	102,500	41.6	706,100	28.9	1,069,300	38.1	713,800	34.6
1893	98,100	39.3	709,100	27.7	1,073,500	25.9	708,200	24.4
1894	93,700	34.8	712,200	23.4	1,077,600	35.6	702,500	30.3
1895	89,400	38.8	715,200	25.7	1,081,700	37.2	696,900	31.3
1896	85,000	43.4	718,200	28.0	1,085,900	35.5	691,200	30.7
1897	....	40.9	....	25.2	....	32.4	....	27.7
1898	....	35.2	....	22.5	....	38.2	....	31.6
1899	....	43.0	....	25.6	....	34.1	....	31.4
1900	....	42.4	....	27.8	....	37.1	....	33.0
1901	32,200	29.2	673,400	24.7	1,069,100	35.0	695,300	32.0
1902	[b]101,200	44.7	[b]674,300	27.9	[b]1,057,100	38.6	[b]656,600	35.5
1903		44.1		28.6		39.0		35.5
1904		42.5		24.5		36.1		34.6
1905		40.3		28.5		30.9		32.2

[a] Winchester bushels.

[b] Area returned by the census of 1901 as intended for the crop named at the time of fall planting; the area actually harvested in 1901, owing to the failure of the wheat crop, differed considerably from these figures.

The estimates of the yield per acre for Denmark are continuous from 1883 to 1905, twenty-three years, and show no tendency to decline. The record of area is not complete, but indicates a considerable decrease for wheat and a fairly constant area in rye, oats, and barley.

Acreage and yields of cereals in France, 1883-1906, by years.

Year.	Wheat.		Rye.		Oats.		Barley.		Corn.	
	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.
	Acres.	*Bush.*	*Acres.*	*Bush.*	*Acres.*	*Bush.*	*Acres.*	*Bush.*	*Acres.*	*Bush.*
1883	16,812,500	17.3	4,249,100	16.4	9,215,700	32.9	2,633,000	22.5	1,556,500	17.7
1884	17,426,800	18.6	4,263,800	17.3	9,135,700	31.2	2,613,100	21.7	1,523,800	18.4
1885	17,190,400	18.2	4,133,900	16.6	9,117,200	30.7	2,361,400	21.7	1,386,000	18.4
1886	17,189,000	17.6	4,038,400	15.8	9,232,000	31.5	2,339,300	22.6	1,357,400	18.7
1887	17,216,900	18.6	4,013,700	16.6	9,192,600	28.2	2,309,000	21.7	1,379,600	21.6
1888	17,243,200	16.0	4,024,900	15.5	9,227,500	29.3	2,208,400	20.8	1,412,100	20.0
1889	17,393,600	17.6	3,952,400	16.5	9,287,500	29.6	2,158,500	21.2	1,379,700	18.9
1890	17,449,800	19.0	3,925,600	17.4	9,342,300	32.6	2,168,400	23.0	1,350,700	17.4
1891	14,220,400	15.2	3,703,000	16.4	10,483,900	32.6	3,022,500	24.7	1,377,900	19.4
1892	17,264,200	18.0	3,809,900	1 .6	9,421,700	28.5	2,203,700	21.2	1,381,100	19.5
1893	17,477,800	15.9	3,781,000	17.0	9,495,000	20.7	2,161,300	16.6	1,402,200	18.8
1894	17,276,200	19.9	3,844,300	19.5	9,591,100	30.7	2,200,000	22.6	1,428,900	19.4
1895	17,301,400	19.6	3,789,400	19.0	9,807,400	31.2	2,200,900	22.6	1,444,400	18.3
1896	16,976,900	20.0	3,707,100	18.8	9,677,300	30.6	2,110,000	22.5	1,442,400	21.2
1897	16,268,800	14.9	3,587,300	13.3	9,860,800	25.7	2,119,900	19.6	1,445,500	21.2
1898	17,207,600	21.2	3,644,600	18.4	9,606,200	33.5	2,012,600	24.1	1,388,000	17.2
1899	17,149,500	21.3	3,679,100	18.3	9,734,200	31.6	1,992,300	23.7	1,386,400	18.5
1900	16,961,400	19.2	3,508,300	16.9	9,739,400	29.3	1,871,100	22.6	1,337,300	16.8
1901	16,787,700	18.5	3,489,400	16.7	9,601,700	26.5	1,838,700	21.8	1,351,900	19.9
1902	16,219,200	20.2	3,290,800	13.9	9,469,400	33.8	1,714,700	25.4	1,242,000	20.3
1903	16,009,200	22.7	3,205,500	18.1	9,498,100	30.3	1,722,500	26.2	1,239,500	20.8
1904	16,133,200	18.6	3,144,300	16.8	9,475,500	30.7	1,741,300	22.6	1,224,600	16.2
1905	16,085,800	20.8	3,136,900	18.7	9,420,100	32.5	1,746,200	24.1	1,241,400	19.6
1906	16,103,200	20.4	3,095,100	16.4	9,525,600	31.0	1,752,800	21.6	....	......

The records for France are continuous for corn from 1883 to 1905, and for the other crops from 1883 to 1906, twenty-four years. The area in wheat, oats, and corn has been fairly constant, while that in rye and barley has considerably decreased. The yield per acre for none of the crops shows any tendency to decrease during this period. From the long-time records from 1815 to 1876, in a table on page 14, as taken from the official report of the French minister of agriculture and antedating this period of twenty-four years, there had been a considerable increase in productivity of the soils of France, particularly prior to 1860.

Acreage and yields of cereals in Germany, 1883–1906, by years.

Year.	Wheat.		Rye.		Oats.		Barley.	
	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.
	Acres.	*Bush.*	*Acres.*	*Bush.*	*Acres.*	*Bush.*	*Acres.*	*Bush.*
1883	4,760,300	18.2	14,399,000	15.4	9,323,700	27.6	4,326,500	22.7
1884	4,755,400	19.2	14,447,200	14.9	9,336,400	31.4	4,287,900	23.9
1885	4,742,600	20.2	14,435,500	15.9	9,357,400	32.1	4,305,500	24.2
1886	4,736,100	20.7	14,428,200	16.6	9,406,100	35.6	4,278,600	25.1
1887	4,743,600	21.9	14,436,500	17.4	9,415,300	31.5	4,277,700	23.7
1888	4,777,300	19.5	14.367,300	15.1	9,470,200	33.8	4,257,900	24.4
1889	4,834,400	18.0	14,336,700	14.7	9,604,000	30.1	4,163,700	21.4
1890	4,843,700	21.5	14,382,200	16.1	9,647,000	35.1	4,112,300	25.5
1891	4,658,700	18.4	13,540,500	13.9	10,266,400	35.4	4,464,400	25.9
1892	4,881,900	23.8	14,032,300	19.2	9,853,800	33.2	4,176,300	26.6
1893	5,051,100	24.8	14,856,600	23.7	9,654,300	29.8	4,020,500	27.7
1894	4,893,900	25.0	14,936,400	22.0	9,678,400	46.8	4,023,000	33.1
1895	4,771,200	24.4	14,563,300	20.9	9,955,100	43.2	4,177,500	31.3
1896	4,761,400	26.4	14,782,200	22.7	9,833,900	41.8	4,142,300	30.8
1897	4,746,000	25.3	14,744,100	21.8	9,881,800	39.9	4,116,800	29.1
1898	4,866,200	27.2	14,690,800	24.2	9,875,600	47.1	4,102,200	32.2
1899	4,982,800	28.4	14,507,600	23.5	9,883,500	48.0	(a)	(a)
1900	5,063,500	27.9	14,715,000	22.9	10,187,600	48.0	(a)	(a)
1901	3,907,800	23.5	14,362,100	22.4	10,900,800	44.6	(a)	(a)
1902	4,725,200	30.3	15,208,100	24.6	10,270,400	50.1	(a)	(a)
1903	4,466,300	29.2	14,857,900	26.2	10,601,700	51.2	(a)	(a)
1904	4,738,300	29.5	15,071,500	26.3	10,352,900	46.2	(a)	(a)
1905	4,762,000	28.5	15,186,000	24.9	10,334,000	43.6	(a)	(a)
1906	4,783,900	30.3	15,077,200	25.1	10,431,600	55.7	(a)	(a)

[a] Not estimated officially.

The records compiled by the bureau of statistics for Germany cover the period from 1883 to 1906, twenty-four years. The area in rye and oats appears to have slightly increased, and that in wheat to have been constant. The estimates for barley are given only until 1898. The yields of wheat, rye, oats, and barley show no tendency to decrease, but, on the contrary, indicate a considerable general increase in productivity, agreeing with opinions, quoted above, of those who have looked into the matter of individual farm records that the productivity of the soils in Germany has increased considerably within historic times. There is certainly no evidence to show a general decrease in productivity.

Acreage and yields of cereals in Italy, 1883–1905, by years.

Year.	Wheat.		Rye.		Oats.		Barley.		Corn.	
	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.
	Acres.	*Bush.*[a]	*Acres.*	*Bush.*[a]	*Acres.*	*Bush.*[a]	*Acres.*	*Bush.*[a]	*Acres.*	*Bush.*[a]
1883 [b]	10,956,600	12.1	395,400	13.2	1,079,900	17.0	835,200	13.1	4,675,200	18.0
1884										
1885										
1886										
1887										
1888										
1889										
1890	10,889,900	12.1	348,400	12.7	1,119,400	17.0	820,400	13.4	4,724,600	15.9
1891	11,124,600	12.7	350,900	13.1	1,107,000	18.0	761,100	12.7	4,709,800	15.4
1892	11,193,800	10.3	355,800	11.9	1,112,000	15.5	773,400	10.3	4,702,400	15.3
1893	11,258,100	12.0	358,300	12.6	1,131,700	16.1	798,100	9.9	4,744,400	17.4
1894	11,302,500	10.8	350,900	12.3	1,151,500	14.8	748,700	11.1	4,697,400	12.7
1895	11,349,500	10.4	338,600	11.8	1,171,300	16.4	733,900	10.1	4,835,800	14.6
1896	11,319,800	12.8					761,100	13.2	4,833,400	16.5
1897										
1898										
1899										
1900										
1901	11,910,400	13.8							4,336,700	23.2
1902	11,737,400	11.6							4,200,800	16.9
1903	11,984,500	15.4							4,171,100	21.3
1904	13,336,200	12.6							4,796,800	19.5
1905	13,134,300	12.2							4,845,500	20.2

[a] Winchester bushels.

[b] Average, 1879–1883.

The records for Italy from 1883 to 1905 are fragmentary. So far as they go they give no indication of a decline in productivity.

Acreage and yields of cereals in the Netherlands, 1883–1905, by years.

Year.	Wheat.		Rye.		Oats.		Barley.	
	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.
	Acres.	*Bush.*[a]	*Acres.*	*Bush.*[a]	*Acres.*	*Bush.*[a]	*Acres.*	*Bush.*[a]
1883	214,100	26.3	493,000	22.0	295,200	38.7	120,000	42.6
1884	219,300	26.9	498,500	21.3	278,300	40.5	116,400	42.0
1885	209,500	30.2	503,800	23.0	283,100	46.1	122,600	44.7
1886	199,300	26.3	503,400	21.3	300,400	48.8	110,100	42.8
1887	210,500	32.7	504,100	27.3	285,300	42.5	111,400	47.0
1888	209,200	25.1	500,200	19.7	281,900	44.5	111,100	38.3
1889	211,000	30.7	501,500	22.6	284,100	47.1	109,700	44.2
1890	200,600	25.9	503,100	22.1	284,300	46.6	104,400	39.8
1891	144,800	24.2	453,500	18.3	377,400	49.1	111,800	40.0
1892	183,400	29.3	495,800	25.1	312,400	48.0	107,700	46.3
1893	175,000	28.4	499,100	24.8	312,200	39.5	103,500	46.1
1894	159,600	26.1	514,700	23.9	327,400	46.1	94,900	38.2
1895	152,900	28.0	519,100	24.7	323,700	48.0	95,700	44.8
1896	153,900	32.8	531,100	25.6	317,400	48.3	97,200	47.0
1897	153,700	27.9	527,400	22.6	331,400	48.7	89,800	41.6
1898	180,600	29.9	530,100	25.8	314,100	52.9	87,000	43.9
1899	177,500	28.7	528,500	24.5	316,800	50.7	87,800	45.2
1900	157,800	29.6	528,900	25.8	324,700	53.3	94,400	48.5
1901	134,600	31.4	532,900	26.6	334,400	55.3	88,700	43.7
1902	152,400	33.5	539,300	25.9	339,800	56.6	90,100	51.6
1903	137,200	31.0	539,000	25.9	357,100	56.3	78,900	48.5
1904	133,600	33.1	534,000	25.3	357,700	52.0	76,300	47.2
1905	150,700	33.7	541,700	25.4	325,800	49.3	81,700	49.1

[a] Winchester bushels.

The records for the Netherlands are complete from 1883 to 1905, twenty-three years. The yields give no indication of decline. The area in wheat and barley has decreased considerably; that in rye and oats appears to have slightly increased.

Acreage and yields of cereals in Roumania, 1886–1906, by years.

Year.	Wheat.		Rye.		Oats.		Barley.		Corn.	
	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.
	Acres.	*Bush.*[a]	*Acres.*	*Bush.*[a]	*Acres.*	*Bush.*[a]	*Acres.*	*Bush.*[a]	*Acres.*	*Bush.*[a]
1886	2,903,700	11.9	570,800	11.2	560,700	17.5	1,371,200	10.6	4,234,400	17.1
1887	2,791,500	17.0	586,600	13.0	582,200	21.2	1,504,600	12.4	4,560,600	10.7
1888	3,104,400	18.6	743,500	19.7	528,600	20.4	1,251,600	18.4	4,283,500	14.7
1889	3,310,900	15.1	424,500	13.5	483,800	13.6	1,263,900	12.5	4,435,800	15.6
1890	3,730,500	13.9	412,900	11.4	441,100	17.2	1,280,200	12.6	4,307,300	14.1
1891	3,811,600	12.7	301,200	12.9	456,900	16.9	1,299,500	17.1	4,184,200	14.3
1892	3,696,900	17.3	328,900	14.1	557,700	19.8	1,384,300	14.9	4,502,500	20.5
1893	3,221,200	18.9	353,400	21.8	622,300	24.8	1,467,600	24.4	4,544,700	16.0
1894	3,441,300	12.7	395,400	14.6	649,100	15.4	1,381,900	12.2	4,367,700	6.8
1895	3,553,400	19.3	537,600	17.2	668,500	15.5	1,365,600	16.4	4,560,300	15.6
1896	3,719,400	19.1	601,500	20.3	696,500	21.1	1,501,700	21.2	4,791,500	13.7
1897	3,941,500	9.2	582,600	11.7	712,000	13.8	1,673,400	12.7	4,583,500	17.4
1898	3,591,900	16.3	477,100	16.0	756,000	23.0	1,618,200	18.3	5,238,800	19.5
1899	4,105,300	6.3	467,900	4.2	766,500	8.2	1,578,200	2.9	4,983,600	5.6
1900	3,927,700	14.4	405,900	14.8	630,800	13.8	1,084,500	13.5	5,029,200	16.9
1901	4,044,000	17.9	522,400	18.3	655,100	25.2	1,244,700	19.5	5,258,400	22.2
1902	3,673,200	20.8	427,000	16.3	793,500	27.6	1,254,700	19.7	5,391,500	12.7
1903	3,967,600	18.6	390,500	18.3	1,054,500	29.8	1,311,900	22.7	5,120,200	15.7
1904	4,254,700	12.6	330,900	6.7	1,052,000	12.0	1,320,100	8.8	5,173,800	3.8
1905	4,838,900	21.4	398,300	33.7	921,000	20.6	1,306,600	21.9	4,882,200	12.1
1906	4,998,500	22.8	454,500	19.6	943,700	27.7	1,380,600	24.3	5,144,500	25.4

[a] Winchester bushels.

The records for Roumania, one of the oldest agricultural countries of Europe, are complete from 1886 to 1906, twenty-one years. The area in wheat, oats, and corn has considerably increased, while that for rye and barley has remained fairly constant. The yields have varied considerably from season to season, thus wheat yielded only 6.3 bushels in 1899, but gave 22.8 bushels in 1906. Rye gave only 4.2 bushels in 1899, but gave 33.7 bushels in 1905. Oats gave 8.2 bushels in 1899, but gave 29.8 bushels in 1903. Barley gave only 2.9 bushels in 1899, but gave 24.4 bushels in 1893 and 24.3 bushels in 1906. Corn gave only 3.8 bushels in 1904 and 5.6 bushels in 1899, but gave 25.4 bushels in 1906. There is no indication whatever of any systematic decline in productivity during this period of twenty-one years, but, on the contrary, the indications are that there has been an increase.

Acreage and yields of cereals in Russia, 1883–1905, by years.

Year.	Wheat.		Rye.		Oats.		Barley.		Corn.	
	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.
	Acres.	*Bush.*	*Acres.*	*Bush.*	*Acres.*	*Bush.*	*Acres.*	*Bush.*	*Acres.*	*Bush.*
1883...	28,879,300	7.9	64,604,600	8.5	34,882,800	16.5	12,441,600	10.9	1,487,800	13.1
1884...		9.3		10.7		14.3		10.8		11.0
1885...		6.2		10.9		11.2		8.1		11.6
1886...		5.7		10.3		16.3		10.7		15.3
1887...		9.7		11.5		17.7		13.5		8.7
1888...	30,601,300	10.3	68,936,000	10.9	36,590,800	15.4	14,397,800	12.7	(*a*)	(*a*)
1889...		6.5		8.3		14.3		8.9		
1890...		6.5		9.2		15.7		11.0		
1891...		5.2		6.8		12.4		9.4		
1892...	32,440,700	7.1	63,200,300	8.8	34,100,200	13.7	15,485,900	10.9		
1893...	32,434,000	10.9	61,961,900	11.1	33,138,000	21.2	15,787,200	18.8	2,258,600	18.0
1894...	32,852,200	10.3	63,230,200	12.8	32,846,500	21.4	15,756,200	15.0	2,089,600	9.3
1895...	31,894,300	9.2	62,595.300	11.5	33,973,300	19.8	15.808,600	13.3	1,917,600	13.0
1896...	34,848,300	8.6	64,238,400	10.9	35,571,600	18.8	16,860,000	12.4	2,184,000	7.9
1897...	35,606,400	6.7	62,646,600	9.1	36,206,500	15.1	17,218,800	11.8	2,211,500	20.6
1898...	36,007,500	9.3	62,283,400	10.2	35,658,500	15.7	17,589,800	14.5	2,351,600	16.8
1899...	38,045,200	8.3	63,405,600	12.7	36,112,400	23.3	17,460,300	10.3	2,406,100	9.4
1900...	39,966,900	8.0	65,738,400	12.6	37.399.300	19.9	17,585,400	10.6	2,709,400	9.4
1901...	41,921,000	7.6	65,950,300	10.3	37,999,800	13.9	18,128,100	10.4	2,701,100	22.5
1902...	42,590,200	10.9	65,871,400	12.3	37,252,400	21.7	18,224,400	15.1	2,860,700	14.1
1903...	43,753,200	10.4	66,511,200	12.1	37,590,400	17.3	19,247,000	15.1	2,760,000	14.6
1904...	45,635,300	11.4	65,643,600	13.6	37,783,100	26.6	20,069,200	14.5	2,901,300	6.5
1905...	48,071,200	9.4	64,689,600	9.7	38,605,700	19.9	20.236,000	13.5	2,870,400	7.9

[a] Statistics corresponding to those of production not available.

The records for Russia are complete, so far as the yields per acre are concerned, from 1883 to 1905 for wheat, rye, oats, and barley, but incomplete for the yield of corn and for the acreage in all the crops. So far as can be seen, the acreage in most of the crops has increased and there is no indication of a decline in productivity.

Acreage and yields of cereals in Servia, 1893–1906, by years.

Year.	Wheat.		Rye.		Oats.		Barley.		Corn.	
	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.
	Acres.	*Bush.*	*Acres.*	*Bush.*	*Acres.*	*Bush.*	*Acres.*	*Bush.*	*Acres.*	*Bush.*
1893............	783,500	11.1	147,800	8.9	261,800	12.5	227,600	11.1	1,314,100	13.8
1897............	691,300	19.4	91,900	20.7	247,300	39.6	185,200	22.9	1,107,900	30.8
1898............	695,900	14.0	111,700	14.2	235,100	27.4	237,200	16.9	1,235,700	22.8
1899............	997,900	11.7	146,100	11.4	250,100	19.8	281,400	13.8	1,148,500	19.2
1900............	766,100	10.6	87,900	7.7	210,600	12.7	184,900	12.2	1,344,900	16.1
1901............	753,200	10.8	93,300	9.5	226,200	14.8	195,000	12.1	1,251,500	15.1
1902............	804,600	14.2	98,400	11.0	248,100	16.3	217,900	16.0	1,296,400	14.2
1903............	860,100	12.7	105,100	10.4	267,600	16.4	234,900	14.6	1,319,100	14.8
1904............	905,400	12.9	111,500	9.2	259,100	12.2	244,700	12.9	1,336,600	7.1
1905............	919,600	12.3	117,500	9.4	258,200	13.7	266,300	13.8	1,365,300	15.5
1906............	921,400	14.3	120,200	13.0	261,500	17.7	270,200	17.6	1,354;500	20.7

The records for Servia are available only from 1893 to 1906. The acreages in wheat, rye, oats, barley, and corn are fairly constant, while the yields show at least no decrease.

The same holds true for Spain with wheat, rye, barley, oats, and corn from 1890 to 1905, with some omission of yearly data; for Sweden with wheat, rye, oats, and barley from 1890 to 1905; and for Switzerland with wheat, rye, and barley from 1888 to 1905.

Acreage and yields of cereals in Spain, 1890–1905, by years.

Year.	Wheat.		Rye.		Barley.		Oats.		Corn.	
	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.
	Acres.	*Bush.*[a]	*Acres.*	*Bush.*[b]	*Acres.*	*Bush.*[b]	*Acres.*	*Bush.*[b]	*Acres.*	*Bush.*[b]
1890	8,558,200	8.8	1,709,200	10.5	3,787,100	10.1	....	....	660,300	24.3
1892	8,366,800	10.4	....	....	....	....	....	....	....	....
1893	7,954,200	11.8	....	....	....	....	....	....	....	....
1894	8,252,100	13.3	1,518,100	11.5	2,518,200	23.0	730,100	17.0	826,000	23.1
1895	7,855,900	10.8	1,488,000	11.7	2,429,300	17.7	653,600	13.6	793,800	19.8
1896	7,825,200	10.1	1,674,200	9.2	2,360,600	13.8	683,100	11.5	993,300	18.4
1897	9,532,600	9.7	1,911,800	9.9	3,109,400	14.7	874,800	26.5	1,095,500	18.0
1898	9,543,100	13.1	1,775,800	11.9	3,689,900	19.7	938,000	18.1	1,036,000	14.7
1899	9,052,500	10.8	1,848,800	11.5	3,465,200	15.6	932,000	16.2	1,160,200	22.1
1900	9,559,700	10.5	1,799,000	11.9	3,432,400	16.5	937,200	17.5	1,175,700	22.1
1901	9,172,300	14.9	1,969,000	14.4	3,301,200	24.2	944,200	24.1	1,156,100	22.3
1902	9,150,100	14.6	1,937,900	13.5	3,599,900	22.6	1,111,800	21.0	1,142,700	22.1
1903	8,983,500	14.4	1,930,800	11.7	3,539,800	18.2	1,115,900	20.6	921,000	20.4
1904	9,023,000	10.6	1,889,900	9.1	3,413,900	15.8	1,103,400	16.7	1,072,600	19.8
1905	8,879,200	10.4	1,854,200	14.3	3,336,200	13.8	1,119,400	19.9	1,148,900	27.7

[a] In 1890, bushels of capacity.
[b] Prior to 1897, bushels of capacity.

Acreage and yields of cereals in Sweden, 1890–1905, by years.

Year.	Wheat.		Rye.		Oats.		Barley.	
	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.
	Acres.	*Bush.*[a]	*Acres.*	*Bush.*[a]	*Acres.*	*Bush.*[a]	*Acres.*	*Bush.*[a]
1890	174,400	23.2	964,500	22.4	1,979,200	32.0	546,200	27.0
1891	175,400	24.7	978,200	22.0	1,992,100	26.4	546,600	23.9
1892	176,300	24.6	957,900	23.3	2,010,800	32.1	550,100	25.2
1893	174,700	22.3	994,600	23.5	2,021,200	27.9	540,300	23.9
1894	175,100	24.9	904,100	19.4	2,022,000	31.4	540,700	26.4
1895	175,800	21.1	997,100	19.2	2,044,600	31.0	542,600	25.7
1896	176,200	26.7	1,007,500	23.0	2,023,000	26.2	538,700	25.2
1897	178,100	26.3	1,012,300	22.7	2,033,100	26.6	542,100	25.2
1898	182,800	25.2	1,014,200	20.4	2,034,700	32.0	545,700	27.2
1899	186,400	24.4	1,012,400	20.0	2,027,500	24.9	545,400	22.9
1900	192,500	28.0	1,015,800	23.3	2,038,200	30.7	537,600	25.7
1901	195,100	21.5	1,013,800	21.5	2,040,100	27.1	537,800	23.7
1902	202,400	23.5	1,017,200	21.9	2,036,100	28.2	531,400	23.1
1903	200,600	27.6	1,013,800	23.0	2,036,300	29.3	528,900	25.7
1904	199,900	25.7	1,016,500	20.4	2,045,900	25.2	526,300	25.6
1905	205,700	26.9	1,014,100	24.1	2,030,800	28.8	514,000	25.0

[a] Winchester bushels.

Acreage and yields of cereals in Switzerland, 1888–1905, by years.

Year.	Wheat.		Rye.		Oats.		Barley.	
	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.
	Acres.	*Bush.*	*Acres.*	*Bush.*	*Acres.*	*Bush.*	*Acres.*	*Bush.*
1888	183,000	19.7	77,000	25.7	136,000	46.7	30,000	27.0
1889		19.5		22.2		43.4		25.4
1890		24.6		27.8		47.5		28.1
1891	174,000	24.2	79,000	25.6	139,000	48.6	30,000	27.5
1892		25.0		28.7		45.6		27.5
1893		18.8		22.5		30.3		22.0
1894	165,000	23.7	79,000	24.8	135,000	43.2	27,000	25.6
1895		20.9		21.5		43.5		25.0
1896		17.9		19.7		38.8		21.3
1897	160,000	21.5	88,000	23.0	144,000	44.0	27,000	24.2
1898	164,000	24.5	88,000	24.2	141,000	48.0	27,000	26.6
1899	164,000	24.7	88,000	25.9	140,000	47.9	27,000	25.8
1900		25.1		25.4		46.8		26.7
1901		22.0		24.0		41.3		24.4
1902		24.3		24.8		47.1		26.2
1903		25.9		26.6		49.4		28.0
1904	157,000	24.7	92,000	26.9	137,000	48.4	20,000	27.7
1905		22.3		24.9		45.4		25.9

Acreage and yields of cereals in Great Britain, 1883–1906, by years.

Year.	Wheat.		Barley.		Oats.	
	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.
	Acers.	*Bush.*[a]	*Acres.*	*Bush.*[a]	*Acres.*	*Bush.*[a]
1883	2,613,200	....	2,292,000	....	2,975,400	....
1884	2,677,000	30.9	2,168,800	35.2	2,915,400	38.7
1885	2,478,300	32.3	2,257,300	36.2	2,940,500	38.0
1886	2,285,900	27.7	2,241,200	33.2	3,081,600	39.0
1887	2,317,300	33.1	2,085,200	32.3	3,088,000	35.8
1888	2,564,200	28.9	2,085,600	33.9	2,882,300	38.4
1889	2,449,400	30.8	2,121,500	32.8	2,888,700	40.5
1890	2,386,300	31.7	2,111,200	36.1	2,903,000	42.7
1891	2,307,300	32.2	2,112,800	35.2	2,899,100	40.0
1892	2,219,800	27.2	2,036,800	35.7	2,997,500	40.0
1893	1,897,500	26.8	2,075,100	29.6	3,171,800	36.7
1894	1,928,000	31.7	2,095,800	35.6	3,253,400	42.9
1895	1,417,500	27.1	2,166,300	32.7	3,296,100	38.2
1896	1,694,000	34.7	2,104,800	34.7	3,095,500	38.0
1897	1,889,200	30.0	2,035,800	33.9	3,036,100	39.7
1898	2,102,200	35.8	1,903,700	36.9	2,917,800	42.0
1899	2,001,000	33.8	1,982,100	35.2	2,959,800	40.0
1900	1,845,000	29.4	1,990,300	32.3	3,026,100	39.1
1901	1,700,800	31.8	1,972,400	32.0	2,996,900	37.9
1902	1,726,400	33.9	1,909,400	35.9	3,057,000	44.0
1903	1,581,500	31.1	1,858,500	33.0	3,140,200	41.0
1904	1,375,200	27.7	1,840,700	32.1	3,252,900	40.4
1905	1,796,800	33.8	1,713,700	35.0	3,051,400	39.4
1906	1,755,600	34.7	1,751,200	35.7	3,043,000	41.8

[a] Winchester bushels.

The records given for Great Britain from 1883 to 1906, twenty-four years, show a decrease in acreage for wheat and barley and fairly constant acreage in oats. There is no indication of any decline in productivity.

Acreage and yields of cereals in Ireland, 1883–1906, by years.

Year.	Wheat.		Barley.		Oats.		Rye.	
	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.	Area.	Average yield.
	Acres.	*Bush.*	*Acres.*	*Bush.*	*Acres.*	*Bush.*	*Acres.*	*Bush.*
1883	94,700	25.5	183,600	35.9	1,381,900	47.7	7,200	22.9
1884	67,900	27.3	167,400	37.4	1,348,400	47.0	7,100	22.2
1885	71,000	28.8	179,500	37.6	1,328,900	47.8	8,400	25.4
1886	69,500	27.0	181,900	35.6	1,322,000	48.7	10,600	23.2
1887	67,200	28.3	162,400	29.8	1,315,100	40.3	10,800	21.6
1888	99,000	25.8	171,300	36.9	1,280,900	48.2	13,900	26.8
1889	89,700	29.9	186,300	40.7	1,239,000	49.8	15,800	25.8
1890	92,300	28.6	182,400	39.2	1,221,000	51.0	14,600	23.2
1891	80,900	32.3	178,300	43.4	1,215,400	54.2	13,400	27.1
1892	75,400	29.4	175,600	38.3	1,226,200	51.6	13,100	25.1
1893	55,000	30.3	169,000	38.3	1,248,300	54.4	13,500	26.5
1894	49,300	31.0	164,800	39.9	1,254,800	53.8	11,900	25.5
1895	36,500	30.4	171,800	38.7	1,216,400	52.4	11,500	26.7
1896	38,000	31.4	173,400	42.3	1,193,600	49.9	13,700	25.5
1897	47,200	28.7	170,700	35.4	1,175,100	48.4	13,100	21.7
1898	52,800	35.2	158,200	44.0	1,165,400	56.1	12,400	25.5
1899	51,900	33.4	169,700	41.8	1,135,500	55.2	12,100	25.7
1900	53,800	31.3	174,200	37.3	1,105,000	55.5	11,400	25.7
1901	42,900	34.2	161,700	42.1	1,099,300	56.6	11,000	27.3
1902	44,200	36.2	167,900	49.3	1,082,100	60.6	9,600	28.1
1903	37,600	31.3	158,800	38.3	1,097,500	53.6	10,000	26.9
1904	30,800	33.7	158,100	34.7	1,078,800	55.8	9,400	26.0
1905	37,900	37.8	154,600	46.4	1,066,800	56.9	10,200	27.0
1906	43,900	34.8	176,500	40.9	1,076,300	58.3	10,300	27.6

The records given for Ireland are complete from 1883 to 1906, twenty-four years. They show a material decrease in acreage for wheat, a slight decrease for oats, and a fairly constant acreage for barley and rye. There is no indication of a decline in productivity.

The largest average yield of wheat per acre for any one year of the countries above-named for the period reported on by the Bureau of Statistics is as follows:

Largest average yield of wheat in different European countries in any year covered by reliable statistics.

	Bushels.		Bushels.
Russia	11.4	Switzerland	25.9
Spain	14.9	Sweden	28.0
Italy	15.4	Germany	30.3
Servia	19.4	Netherlands	33.7
Austria	20.2	Belgium	35.1
Hungary	21.8	Great Britain	35.8
France	22.7	Ireland	37.8
Roumania	22.8	Denmark	44.7

The largest average yield of wheat for any one year in several groups of States in the United States for forty years, as compiled from the Bureau of Statistics' records, is as follows:

Largest wheat yield in any year for forty years in several groups of States.

	Bushels.
Virginia, North Carolina, South Carolina, Georgia, and Alabama	11.2
Kentucky and Tennessee	14.3
Texas and Arkansas	15.2
Wisconsin, Michigan, Iowa, and Illinois	16.6
Minnesota, Nebraska, Kansas, and Missouri	16.7
Ohio, West Virginia, and Indiana	17.9
New Jersey, Pennsylvania, Delaware, and Maryland	19.7
California	20.0
Ohio, Indiana, and Illinois	20.2
Oregon	21.1
Maine, New Hampshire, Vermont, and New York	22.4

It is safe to say that the soils of Europe have been occupied for agricultural purposes for one thousand to two thousand years longer than those of the United States, yet during the past twenty-five years ten out of the sixteen countries of Europe reported upon have produced more wheat per acre than any of the groups of States in the United States during the past forty years.

A careful examination of all the available data regarding crop yields in the European countries, and a comparison of these with the yields of the newer lands of the United States, fails entirely to justify the conclusion or general impression that the productivity of the soils of Europe is decreasing. On the contrary, one would be justified in concluding that with the general increase in education and incentive the sum of the individual failures at the present time is rather more than counterbalanced by the successes, and on the whole there has been an increase in productivity within historic times.

EVIDENCE PRESENTED BY THE YIELD OF CROPS IN THE UNITED STATES.

The impression is strong and widespread that the productivity of the soils of the United States is decreasing. It is believed that the soils are wearing out through loss of mineral plant food removed by crops. It is believed that in the "early seventies" yields of 50 to 60 bushels of wheat per acre were common over the prairie soils of the Northwest.

Whatever may have been accomplished on individual farms at that time or since or however much we may be impressed with the individual failures which come under our personal observation, a careful study of the official records of the Bureau of Statistics of the Department of Agriculture[a] fails entirely to bear out the general impression that the yields are declining in the United States as a whole or in any considerable portion of the area, and gives us a very different and much more modest impression of the average yields obtained in the "early seventies."

In 1885, about twenty-four years ago, Prof. I. P. Roberts, of Cornell University, made inquiry of the Department of Agriculture regarding this question of wheat yield and the statistician, J. R. Dodge, sent him the following statement:[b]

> In response to your inquiries I may give a few facts tending to show the increase of rate of yield of wheat, the principal food-grain of countries of high civilization, as the result of progressive and scientific agriculture. It is a very significant fact that the countries of high natural fertility of virgin soils show the lowest rates of yield, while the soils of countries, long cultivated under systematic and enlightened methods, give much higher returns. Thus in Australasia the rate of yield is about 12 bushels per acre, as in this country. In India the average is about 9 bushels.
>
> Coming to Europe, the average of Russia may be said to be 6 to 7 bushels, produced by careless cultivation in the rich soils of the black-earth belt and in other sections. The average of the valley of the Danube differs little from the average yield of this country. The average of Portugal is usually placed at about 13 bushels.

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[a] See the following bulletins of the Bureau of Statistics, U. S. Department of Agriculture:

Bul. 56, Corn Crops of the United States, 1866–1906.
Bul. 57, Wheat Crops of the United States, 1866–1906.
Bul. 58, Oat Crops of the United States, 1866–1906.
Bul. 59, Barley Crops of the United States, 1866–1906.
Bul. 60, Rye Crops of the United States, 1866–1906.
Bul. 61, Buckwheat Crops of the United States, 1866–1906.
Bul. 62, Potato Crops of the United States, 1866–1906.
Bul. 63, Hay Crops of the United States, 1866–1906.

[b] Report of the Commissioner of Agriculture for 1885, p. 375.

In 1873, when a series of good wheat seasons had been enjoyed in Europe, an international statistical commission[a] fixed upon the following average rates of yield for those countries of Europe that furnished statistical data to determine them:

	Bushels.		Bushels.
Great Britain	29.9	Saxe-Weimar	17.2
Saxe-Altenburg	28.7	France	17.1
Belgium	27.9	Baden	16.9
Saxony	27.0	Wurtemberg	16.6
Holland	24.8	Roumania	13.8
Norway	23.3	Portugal	13.2
Denmark	19.5	Hungary	12.6
Finland	17.8		

In the thirteenth century, according to J. E. Thorold Rogers, the rate of yield, while variable and not accurately determined, was not thought to exceed a quarter of 8 bushels. Arthur Young, in 1770, made the average in England 23 bushels per acre, and Sir James Caird, in 1850, 26½ bushels. Though the yield is given in the above table of the commission at 29.9 bushels, Sir James Caird, in 1868, thought 28 bushels near the real average. There was a large yield for several years afterwards, but after 1873 there was a period of low yield, scarcely equal to the average of Ireland, 24 bushels.

In France, according to Alexander Moreau de Jonnes, in his *Statistique de l'Agriculture of France*, the average yield was 8 hectoliters per hectare, or a little more than 9 bushels per acre. In 1873, over 11 bushels; in 1840, 14 bushels. It may be assumed that the yield per acre in France is now very nearly double the rate two hundred years ago. It is not much over a half a century since the average rate of France passed the present yield in this country.

Evidence from Russia is not very explicit, though its tenor is favorable to gradual increase of rate of yield. It has conditions much like our own, large areas of new and cheap lands, which tend to prevent rapid change of rate, while the elements of improvement are in active movement locally. As to this country, the average has not materially increased for the whole area, because that area is geographically changing. It is shifting from east to west and to northwest, taking in fresh prairie lands and giving up to grass and other crops a part of the more eastern acreage. Yet, on the whole, it is not so much abandonment of older areas as the taking up of western lands in the increase of breadth. This change perpetuates substantially the original conditions, and keeps the average nearly the same, viz, about 12 bushels per acre for a series of years throughout the entire breadth in wheat.

I find no evidence that the yield is decreasing in this country. In a given field in the spring-wheat region, the rate will increase for a year or two after breaking, then begin to decline, not from soil exhaustion, but from preoccupation of the soil with weeds. Yet there is evidence that the rate of yield is increasing in Western New York, Southern Michigan, and the wheat counties of Ohio, Indiana, and Illinois, and in Maryland, where some semblance of rotation exists and cultivation has some pretense of a scientific basis. In those regions the average is already about the same as in France, and is 20 to 50 per cent higher than the general average. In 1879 the areas above mentioned averaged about 18 bushels per acre, while spring wheat, grown year after year amid weeds and without any real cultivation of the soil, only produced 11 bushels per acre.

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[a] A summary of the results of the International Statistical Congress held at St. Petersburg in 1872 is contained in the Report of the Commissioner of Agriculture, p. 254, 1876.

Again, in 1886, Dodge makes the following statement:[a]

> It is sometimes assumed that the yield of wheat is declining in this country. This conclusion is not warranted by the facts. The average for six years past is 12.1 bushels per acre, ranging from 10.4 to 13.6 annually. The average of the preceding ten years was 12.4. Almost any period of five to eight years has heretofore made an average very slightly exceeding 12 bushels. The older wheat-growing States make larger averages than the newly settled regions, not because the land is richer, but because it is more thoroughly cultivated. In the future, as rotation and thorough culture prevail, the average rate of yield must be expected to increase, as it has done in some sections already.

With the complete records of the Bureau of Statistics extending over forty years we should be in a better position to draw conclusions than was Dodge, with less than half the records. Nevertheless it is extremely difficult to draw positive conclusions from estimates, even with records extending over a period of forty years, in a country which has been rapidly developing and when the basis of the estimates, namely, the area is rapidly increasing and where the seasonal variations are large. It may not be safe to assume, as may be done with the European records, that the sum of individual failures at present is rather more than counterbalanced by the sum of individual successes as compared with the past, and to say that there is an indication of increased productivity, since the agricultural history of this country is not old enough nor is the period covered by statistics long enough to justify such a positive statement. The records are, however, sufficient for the statement that there is no evidence to prove a decrease in productivity.

THE YIELD PER ACRE OF WHEAT IN THE UNITED STATES.

The average yield of wheat in the United States for the past forty years from 1867 to 1906 is, according to the records of the Bureau of Statistics, 12.7 bushels per acre.

The following table gives the yields for each year in the several decades:

Average yield per acre of wheat in the United States from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
11.6	13.9	12.1	13.4
12.1	13.1	11.1	15.3
13.6	13.8	12.9	12.3
12.4	13.1	11.1	12.3
11.6	10.2	15.3	15.0
11.9	13.6	13.4	14.5
12.7	11.6	11.4	12.9
12.3	13.0	13.2	12.5
11.1	10.4	13.7	14.5
10.5	12.4	12.4	15.5
12.0	12.5	12.7	13.8

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[a] Report of the Commissioner of Agriculture for 1886, p. 373.

The straight or unweighted averages for the several decades, 12.0, 12.5, 12.7, 13.8, indicate a gradual and regular increase in productivity. However, when these figures are platted and a medial line drawn through the figure, there is indicated a slight downward curve with the low point of the curve about 1886–87, the end and beginning of a decade, which accounts for it not being shown in the averages.

A corresponding depression is noticed in the records for nearly all the States and indicates very strongly a general seasonal influence over most of the country during the middle of the forty-year period. In fact, a critical examination of all the data presented in this bulletin indicates that a full forty-year period is the smallest unit which should be taken to minimize seasonal fluctuations in order to give a normal average which can safely be used as a basis for comparison of relative productivity. Certainly ten-year and even twenty-year averages can not be used with perfect assurance.

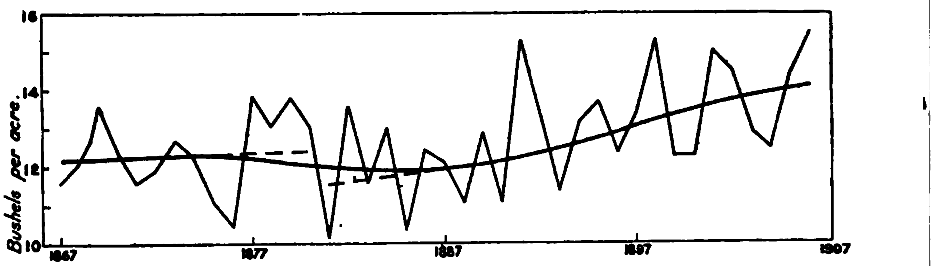

FIG. 1.—Average yield of wheat in the United States from 1867 to 1906.

So far as the available data can be relied upon for any conclusion, it may be said that there is on the whole a decided tendency toward increased productivity of the soils of the United States.

We must, however, see if this has been influenced to any significant degree by the extension of wheat growing into new areas, as the mean acreage of wheat in the United States for the several decades is given as 21,661,078, 35,060,189, 36,583,809, and 45,540,593. There are 33 States which have a higher average yield per acre than the United States as a whole, and 15 States having a lower yield. If proportionately more of the increase in acreage has occurred in the 33 States having above the average yield of the country as a whole, the increase in yield per acre in the United States would be accounted for. To determine this, we must take up the records of the individual States or groups of States having somewhat similar yields and similar increases or decreases in acreage.

In the following table the States for which the Bureau of Statistics has full forty-year records (except California, which has records extending for only thirty-nine years) are arranged in the order of the average yield per acre of wheat over this period:

Average yield of wheat in bushels per acre in different States for forty years, 1867 to 1906.

	Bushels.		Bushels.
Vermont	18.5	California	12.9
Maine	16.5	*Average for United States*	12.7
New York	15.7	Iowa	12.4
New Jersey	14.5	Missouri	12.2
Michigan	14.5	Texas	11.5
Pennsylvania	14.2	West Virginia	10.6
Ohio	14.1	Kentucky	10.5
Kansas	13.9	Virginia	9.1
Wisconsin	13.7	Arkansas	8.9
Minnesota	13.6	Tennessee	8.2
Maryland	13.3	Mississippi	8.1
Illinois	13.2	Alabama	7.6
Nebraska	13.1	Georgia	7.1
Indiana	13.1	North Carolina	6.9
Delaware	13.1	South Carolina	6.6

The most obvious fact brought out by this table is that the arrangement shows roughly three geographical groups of States, the Southern States having very small yields, the New England States with New York showing the largest yields (two or three times as large as the Southern States), and the great wheat States of the Middle West coming between.

The average yield for each of the four decades from 1867 to 1906 is given for each of the States in the table prepared by the Bureau of Statistics and published in the Crop Reporter for December, 1908. These show a general tendency to increase, but there are fluctuations which make it difficult to draw satisfactory conclusions, since the seasonal variations have not been entirely eliminated even over so long a period, and we know that great changes have occurred in the acreage of certain of the States; it is important to see the effect, if any, of these changes upon the average yield.

For the present purpose it has been deemed best to group the States with due regard to equality of yield per acre and increase or decrease in acreage in order to further minimize the influence of seasonal variation of climate.

In considering the change in the productive capacity as measured by the yield per acre of crops, it is necessary to have records covering a sufficiently long period to reduce the seasonal variations to a very small amount, but it is unfortunate that we have available no continuous records in this country for more than forty years, either for a State or for any individual farm or constant area of any soil type.

The nearest approach to this constant acreage and uniformity of yield in several States, where, at the same time, records of the Bureau of Statistics are available for forty consecutive years, is in what may be taken as two groups of States, namely, Maine, New

Hampshire, Vermont, and New York; and New Jersey, Pennsylvania, Delaware and Maryland. In all of these States agriculture is old and in the past forty years there has been relatively very little new land to take up.

Average yield per acre of wheat in Maine, New Hampshire, Vermont, and New York, from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
13.3	17.0	13.2	17.7
13.1	16.0	15.0	20.6
16.7	14.5	15.0	20.1
15.0	14.3	15.1	19.3
15.5	15.3	16.7	18.6
15.3	14.6	16.6	20.3
13.9	14.2	15.6	21.4
15.9	15.8	19.7	19.9
14.1	15.6	21.4	20.9
14.2	16.2	20.9	22.4
14.7	15.4	16.9	20.1

In Maine and Vermont the acreage in wheat, at all times small, has been reduced considerably in later years, and the yield per acre has materially increased during the successive decades. It may be argued that this increase in yield per acre is due to the abandonment of lands less well adapted to wheat; but in New York, which has a very much larger acreage, but with much smaller change in acreage, the yield has increased nearly as much. If we take the figures representing the yield per acre for each of the States for the four decades as an indication only of productivity and, regardless of acreage, add them together, we get a factor of relative productivity for the different decades in which the seasonal fluctuations will be more nearly eliminated than if we had used the weighted averages, and while the results show the same order of increase we get a smoother curve.

Reducing these sums to figures approximately equal to the average yield per acre of the several States, by dividing by the number of years, the relative yields of the several decades are represented by the figures 14.7, 15.4, 16.9, and 20.1, indicating a decided and progressive increase in the productivity of the lands.

These States, however, show a remarkable falling off in the total land values and contain many so-called "abandoned" farms, but so far as the production of wheat is concerned this is not due to a decline in fertility or to the wearing out of the soil; the explanation must be sought in changed economic conditions connected with the relative cost of production and other conditions which are outside of the scope of this discussion.

The accompanying diagram shows even more clearly than the average figures for the decades the rate of increase in productivity.

The effect of the intelligent reduction of acreage mentioned as a possible factor in increasing the yield per acre of wheat in the New England States and New York can not hold with the second group of States above mentioned, as the acreage has varied but little in the States of New Jersey, Pennsylvania, Delaware, and Maryland. Nevertheless, by combining the yields per acre as productivity factors for these States, as was done with the first group, the relative order of productivity for the different decades is represented by the figures 12.7, 12.9, 13.5, and 16.1, again showing a regular increase for a group of some of the older States, where the land has practically all been settled for much longer than the forty years covered by the data.

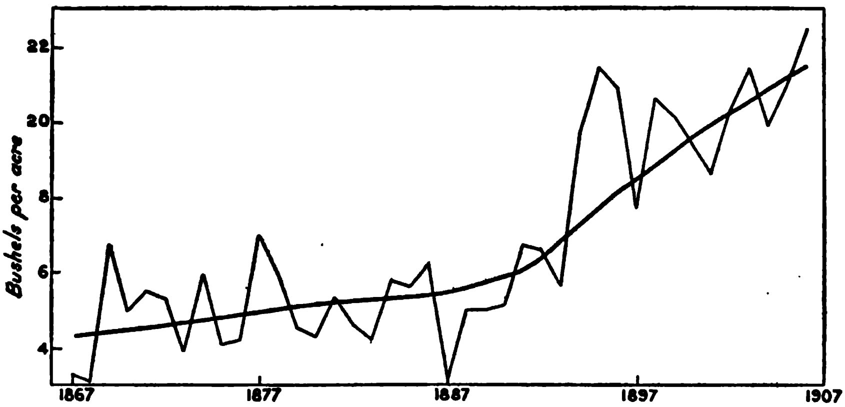

FIG. 2.—Average yield of wheat in Maine, New Hampshire, Vermont, and New York from 1867 to 1906.

Average yield per acre of wheat in New Jersey, Pennsylvania, Delaware, and Maryland, from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
11.7	13.5	10.0	19.7
12.2	14.0	13.1	15.9
14.2	13.8	11.9	13.8
11.1	15.0	11.4	18.1
14.4	11.8	14.7	17.4
10.5	13.4	13.8	15.8
13.2	12.3	14.2	13.1
13.0	12.5	14.7	13.9
12.6	9.9	14.4	15.9
13.8	13.3	16.1	17.0
12.7	12.9	13.5	16.1

The accompanying diagram brings out one detail which is not clearly apparent in the table of figures or in the averages for the decades, namely, that in the latter part of the second decade and the first part of the third decade there was a marked decline in productivity, evidently due to seasonal influences.

The general trend of the curve is undoubtedly upward. In considering the estimates of the Department of Agriculture it must be remembered that as soon as the actual figures are available from each decennial census the estimates of the bureau on the acreage and yield are adjusted to meet the ascertained facts, and this may have an influence on the estimates of the yield per acre. It is significant that this departure from the general trend of the curve begins at 1881 and ends at 1891, when the census figures were available. It will be seen in considering the yield of corn that this factor has undoubtedly influenced the estimates to a notable extent, especially for some of the States. It is of course apparent that this method of diagrammatical representation is a very rigorous expression of estimates, and brings out inequalities which might not be brought out by a similar diagram of ascertained facts, if such facts could be established each year, as is done each decennial year by the Census Bureau. Such definiteness is not possible under the methods which must be employed by the department, nor is it claimed for these estimates. Anyone at all familiar with statistical work will clearly understand these limitations.

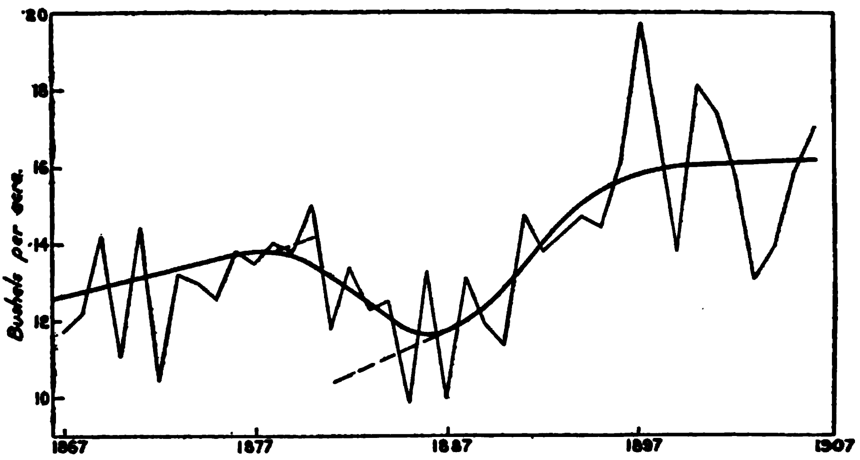

FIG. 3.—Average yield of wheat in New Jersey, Pennsylvania, Delaware, and Maryland from 1867 to 1906.

In the States of Virginia, North Carolina, South Carolina, Georgia, and Alabama the average yields per acre have been closely comparable and the acreage not very different either among the States or during the period of forty years. The averages are not so regular as in the last two groups of States, in that the figure representing the average for the second decade is six-tenths of a bushel lower than the first, and for the third decade five-tenths of a bushel less than for the first decade.

Average yield per acre of wheat in Virginia, North Carolina, South Carolina, Georgia, and Alabama, from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
7.4	9.0	6.8	9.6
6.3	6.7	5.8	11.2
8.1	8.4	6.8	7.2
8.3	6.5	4.8	9.8
6.1	6.7	7.4	9.1
8.2	7.5	7.3	5.7
6.7	6.1	8.2	7.1
7.7	6.5	7.1	9.2
7.7	5.1	7.3	8.1
7.3	5.8	7.9	10.4
7.4	6.8	6.9	8.7

The medial line of the diagram shows a depression. Whether this is real or is influenced in any way by a readjustment to conform to the facts established by the census of 1880, the figures for which are known to have been available in 1881, and by the census figures of 1890, can not now be established with any certainty. In any event the general trend of the line is upward rather than downward as popularly supposed.

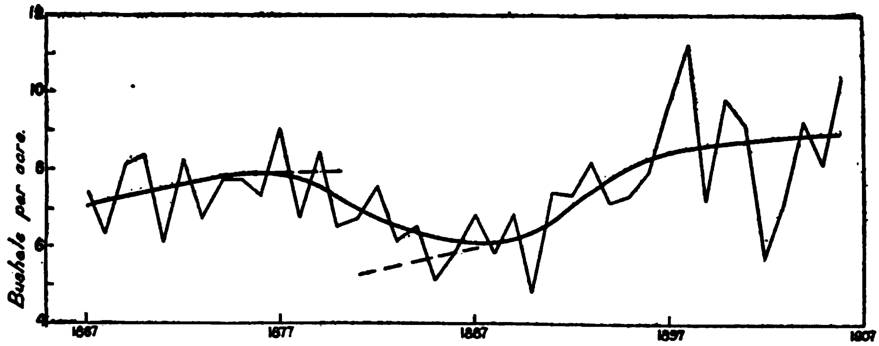

FIG. 4.—Average yield of wheat in Virginia, North Carolina, South Carolina, Georgia, and Alabama from 1867 to 1906.

Ohio, Indiana, and Illinois form another group of States having nearly the same acreage and the same yields per acre in which the yield per acre for the past forty years has apparently at least held its own or even increased, the relative productivity of the three States for the four decades being represented by the figures 11.9, 14.2, 13.8, and 13.9.

Average yield per acre of wheat in Ohio, Indiana, and Illinois, from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
11.2	15.3	13.9	12.6
11.9	15.9	11.6	14.5
13.7	19.5	15.1	11.3
12.3	17.0	11.2	8.1
12.5	10.8	17.7	16.2
12.1	16.4	14.8	17.0
12.2	10.1	13.4	10.7
12.9	13.1	18.5	11.5
9.7	9.8	11.2	17.1
10.7	14.5	10.9	20.2
11.9	14.2	13.8	13.9

Two areas of slight depression are shown in the medial curve of the diagram, but as a whole the line shows a tendency to rise.

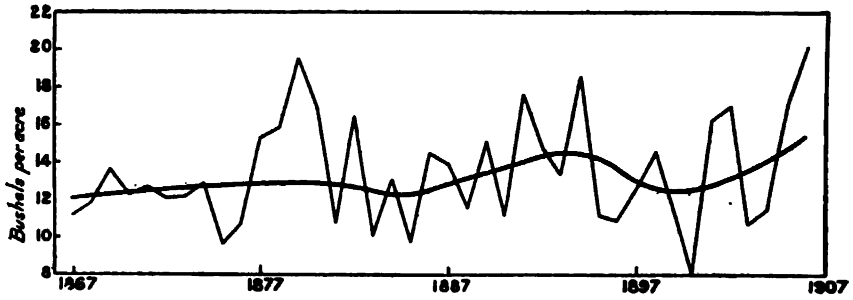

FIG. 5.—Average yield of wheat in Ohio, Indiana, and Illinois from 1867 to 1906.

We now come to two groups of States showing some marked differences in acreage in the last forty years.

The acreage in wheat in the first of these groups, embracing Wisconsin, Michigan, Iowa, and Illinois[a] has declined considerably. The total average acreage in wheat for the four decades is 7,336,041, 8,525,988, 5,697,582, and 4,572,012. The relative yield per acre of the group of States for the corresponding decades may be expressed by the figures 12.4, 13.3, 13.8, and 14.3, as shown by the following table:

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[a] The object in averaging the yields of several States being to decrease the seasonal variation and acreage variation, it has been deemed best to use the data for Illinois in two groups, since this State may be classed geographically with Ohio and Indiana, and with Iowa, Wisconsin, and Michigan. Similarly, the data for a State has been used below in more than one group of States, as desired, to secure as wide a basis for the averages as is possible.

Average yield per acre of wheat in Wisconsin, Michigan, Illinois, and Iowa, from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
12.2	15.9	12.2	12.0
12.9	13.4	12.4	16.6
13.7	15.2	14.5	11.7
13.0	13.4	11.7	12.9
12.3	9.3	16.4	15.3
12.7	14.7	13.5	16.6
13.8	11.9	12.4	13.0
12.2	13.5	16.3	12.7
11.9	12.7	14.8	16.3
9.1	13.4	14.2	16.2
12.4	13.3	13.8	14.3

This shows an apparently regular increase in productivity and by referring to the diagram it is seen that with one slight depression the direction of the medial line is upward, indicating an increasing productivity. It may be argued, as in the case of the New England States, that in restricting the acreage the lands less well adapted to wheat have been first abandoned and the average yield increased in this way, but this is negatived by a similar increase in productivity in groups of States where the acreage has remained constant or has increased.

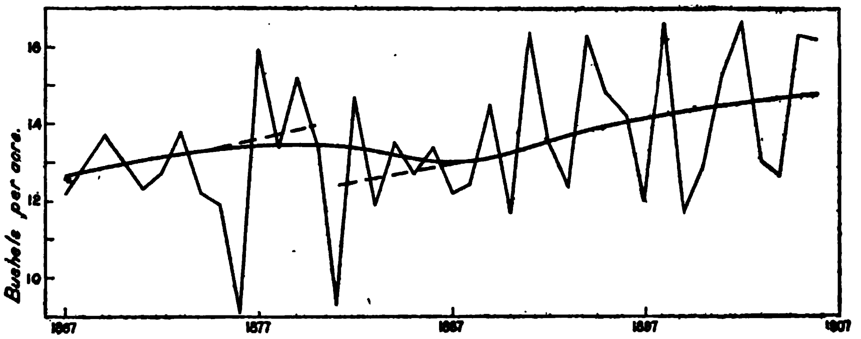

FIG. 6.—Average yield of wheat in Wisconsin, Michigan, Illinois, and Iowa from 1867 to 1906.

We have another group of closely adjacent States, namely, Minnesota, Nebraska, Kansas, and Missouri, where the acreage has largely increased the sum of the mean acreage for the several decades, being 2,693,576, 7,799,182, 8,654,331, and 14,364,930. The relative yield per acre of the group may be expressed by the figures 13.8, 12.6, 12.6, and 14, showing an apparent increase. The figures for Minnesota and Kansas, it is true, appear to show a slight decrease, but the seasonal variations in both these States are large, so large they are not eliminated in the ten-year periods. For example, in Nebraska in the first and third decades the difference between the highest and lowest yield is actually greater than the average yield for forty years. The larger the group of States that can be compared, other things being equal, the better.

Average yield per acre of wheat in Minnesota, Nebraska, Kansas, and Missouri, from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
13.5	15.3	11.9	13.0
15.0	13.1	11.4	14.1
16.7	12.2	14.5	10.9
14.4	11.3	11.9	13.2
12.7	9.1	15.4	16.1
12.3	13.9	13.5	16.3
15.2	14.0	9.1	12.9
13.1	14.5	11.6	12.6
13.2	10.1	13.7	14.8
11.7	12.4	12.6	15.7
13.8	12.6	12.6	14.0

The accompanying diagram shows the medial line describing one great uniform curve with the points of origin and ending approximately at the same elevation. Some doubt is cast upon the validity of this curve on account of the uncertainty as to what influence, if any, the census figures available in 1881 had upon the basis of estimating the yields for the decade ending with the publication of the figures for the 1890 census. If an adjustment was made so that the medial line need not be continuous the most probable course would be represented by the broken lines. If the continuous curve is followed there is no evidence of permanent decline in productivity. If the broken line is followed there is evidence of a general and continuous increase in productivity.

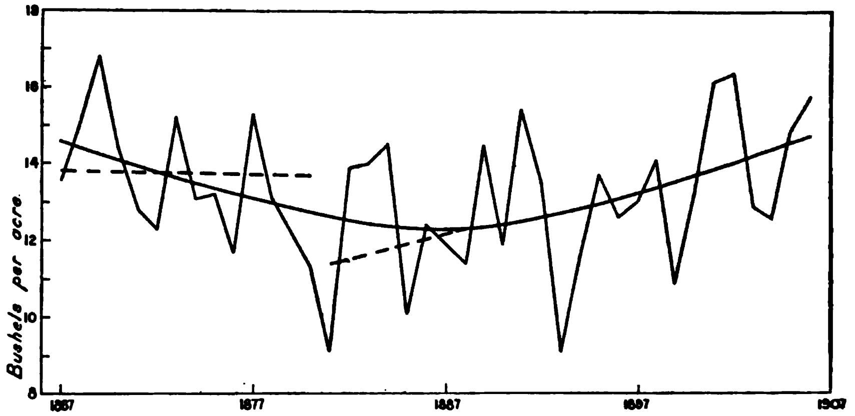

FIG. 7.—Average yield of wheat in Minnesota, Nebraska, Kansas, and Missouri from 1867 to 1906.

We are justified in concluding in this group of States where the acreage has increased the productivity has increased, as was shown in the last group of States where the acreage has decreased.

Combining the data for all eight of the States just named—Wisconsin, Michigan, Iowa, Illinois, Minnesota, Nebraska, Kansas, and Missouri—we get for the average figures for the four decades 13.1, 13, 13.2, and 14.1.

Average yield per acre of wheat in Wisconsin, Michigan, Iowa, Illinois, Minnesota, Nebraska, Kansas, and Missouri, from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
12.8	15.6	12.0	12.6
14.0	13.3	11.9	15.3
15.2	13.7	14.5	11.3
13.7	12.3	11.8	13.1
12.5	9.2	15.9	15.7
12.5	14.3	13.5	16.4
14.5	13.0	10.7	12.9
12.6	14.0	13.9	12.7
12.6	11.4	14.2	15.5
10.4	12.9	13.4	15.9
13.1	13.0	13.2	14.1

In the diagram we can only show the medial line as making one long curve sloping gently downward from the origin during half the period, and then upward to the end point, which is somewhat higher than the origin, as though the seasonal changes had passed through a single cycle of forty years. If there was an adjustment of the department's estimates in 1881 to conform with the data of the Tenth Census, then it would have shown a broken line, each section rising slightly from the two points of origin.

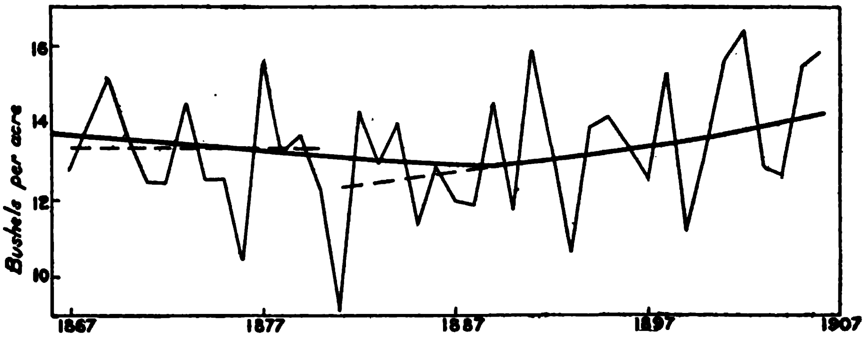

FIG. 8.—Average yield of wheat in Wisconsin, Michigan, Iowa, Illinois, Minnesota, Nebraska, Kansas, and Missouri from 1867 to 1906.

Kentucky and Tennessee have each maintained a fairly constant acreage for the forty-year period. The figures representing the average yield by decades, 8.8, 8.1, 9.7, 10.9, indicate a gradual increase save for a slight decrease in the second decade. The diagram shows this to be due to a slight depression originating at the same period as in several of the other groups of States.

Average yield per acre of wheat in Kentucky and Tennessee from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
8.4	10.5	9.1	12.4
7.6	7.2	9.4	14.3
9.7	11.0	9.3	8.9
9.4	7.4	8.2	11.5
5.6	6.8	11.2	11.5
10.8	10.7	10.7	8.8
8.1	6.7	10.3	7.8
9.8	8.8	10.3	11.5
9.3	3.4	9.9	9.3
9.2	8.9	8.6	13.3
8.8	8.1	9.7	10.9

On the whole there can be no doubt that the productivity has shown a decided tendency to increase in this group of States.

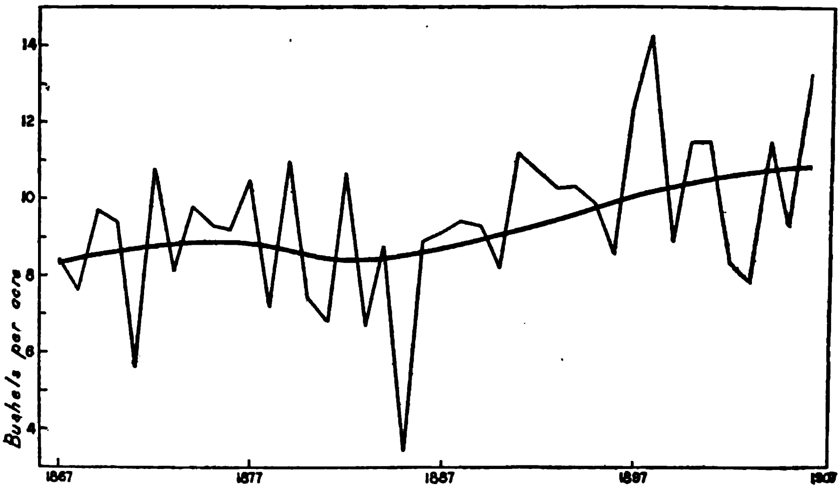

FIG. 9.—Average yield of wheat in Kentucky and Tennessee from 1867 to 1906.

With Ohio, West Virginia, and Indiana we have a group of States where the acreage showed a decided increase during the first three decades. The total acreage in wheat for the four decades is 3,503,127, 5,283,871, 5,530,392, and 4,588,086. The figures representing the average yields for the several decades, 11.6, 13.3, 12.4, 13.1, show a tendency toward increased productivity save for a relatively high yield in the second decade.

Average yield per acre of wheat in Ohio, West Virginia, and Indiana, from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
10.9	13.9	12.0	14.4
11.6	15.2	10.2	15.5
13.9	17.6	13.2	11.1
12.1	15.5	10.5	7.0
12.0	11.5	15.2	14.0
11.5	14.3	13.0	13.6
10.9	10.1	13.4	11.3
12.9	12.8	16.5	10.3
8.4	8.8	11.0	15.9
11.3	13.5	9.4	17.9
11.6	13.3	12.4	13.1

When the results are represented diagrammatically this increase is not so apparent, as the medial line is wavy and shows clearly neither an increase nor a decrease in productivity.

In Texas the acreage has increased about ninefold, comparing the total acreage of the first decade and of the last. In Arkansas the acreage has remained fairly constant. Combining the data for the two States the figures representing the average yields of the four decades show the highest yield in the first decade with an increasing yield from the second to the fourth.

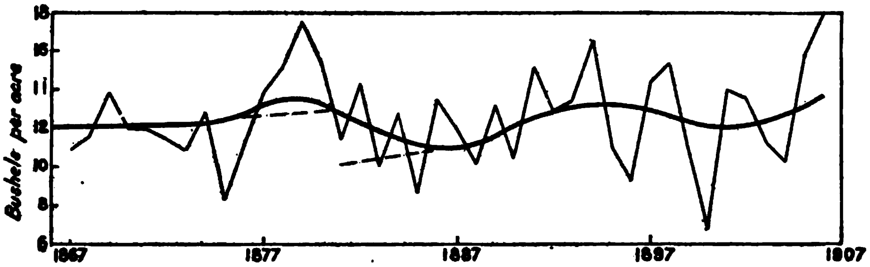

FIG. 10.—Average yield of wheat in Ohio, West Virginia, and Indiana from 1867 to 1906.

Average yield per acre of wheat in Texas and Arkansas, from 1867 to 1906 by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
9.4	10.5	9.9	13.2
9.8	11.0	10.2	12.9
11.5	7.8	9.0	9.9
11.3	7.5	7.1	14.3
9.9	8.9	10.8	8.9
14.5	8.2	10.3	9.1
13.5	7.3	9.3	10.2
11.5	8.8	11.9	10.4
15.2	8.9	7.6	8.4
10.6	9.0	9.9	11.2
11.7	8.8	9.6	10.9

A probable reason for this is shown in the diagram (fig. 11). It was due to three phenomenally high yields in the first decade and probably to an adjustment of the department's estimates in 1881 to conform with the figures of the Tenth Census. If an adjustment was made the curve should be broken, and its true position may be represented by the broken lines on the diagram.

The acreage in wheat in California has been fairly constant for the forty-year period. The figures representing the average yields for the four decades, 14.6, 12.9, 12.7, 11.6, show an apparently regular decrease in productivity, and this State is popularly supposed to represent an extreme case of declining yields in wheat and loss of fertility due to continuous wheat culture.

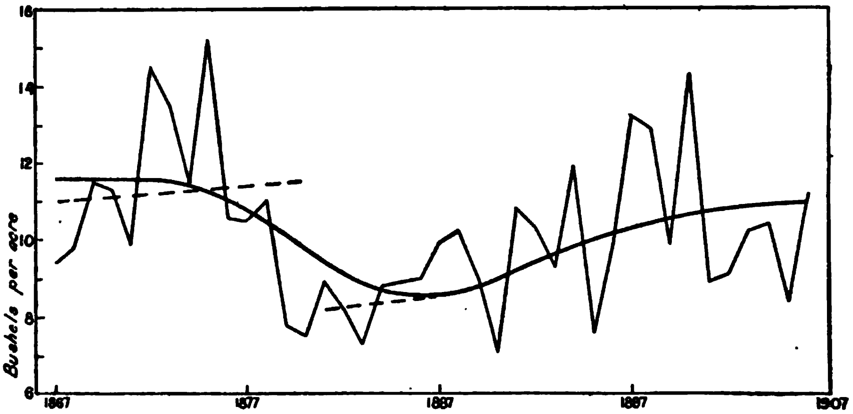

FIG. 11.—Average yield of wheat in Texas and Arkansas from 1867 to 1906.

Average yield per acre of wheat in California from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
....	9.5	11.0	10.0
20.0	17.0	12.1	9.1
18.2	14.0	13.3	14.1
19.0	16.0	12.0	10.3
11.0	12.0	13.0	13.0
12.2	13.0	13.0	10.9
13.5	13.0	13.3	11.2
13.2	13.2	11.3	10.8
11.0	9.4	13.0	9.3
13.0	11.6	14.6	17.1
14.6	12.9	12.7	11.6

When the data are represented diagrammatically, the medial line has a slight tendency downward.

There are three relatively very high yields in the first decade, two in the second, and one in the last year of the last decade; but on the whole practically little change is indicated by the general direction of the line.

The data for Oregon show great fluctuations from year to year. The figures in the table show lower yields in the second and third decades than in the first and last. This is brought out more clearly in the diagram, which seems to show one long, uniform curve showing a somewhat decided tendency to decrease until about the end of the second decade, and an equally decided increase during the last two decades.

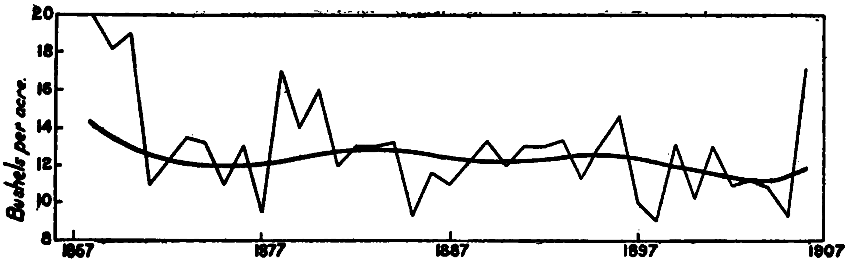

FIG. 12.—Average yield of wheat in California from 1867 to 1906.

Average yield per acre of wheat in Oregon from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
....	20.0	17.5	17.0
....	21.0	16.3	20.5
19.0	16.0	16.2	19.2
19.5	17.0	14.5	13.8
19.2	17.2	19.0	21.1
18.2	16.7	15.7	20.0
19.0	16.5	17.5	18.2
19.5	18.0	17.7	19.0
17.6	15.9	20.0	18.6
17.0	12.6	17.0	20.0
18.6	17.1	17.1	18.7

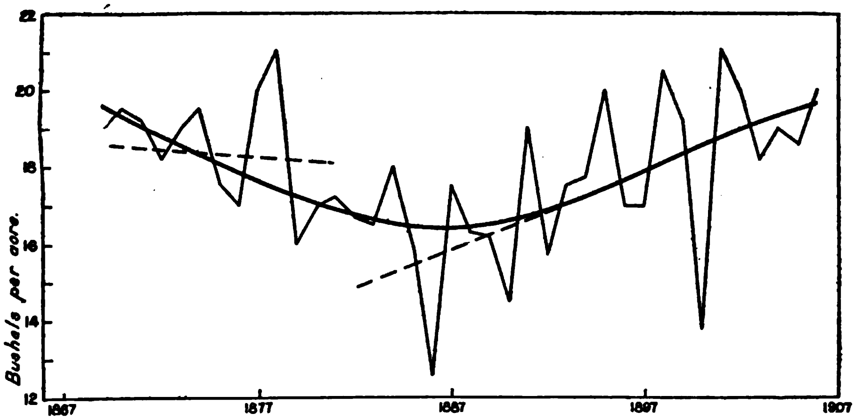

FIG. 13.—Average yield of wheat in Oregon from 1867 to 1906.

The following table gives, in decades, the data for the States having records covering less than forty-year periods and more than twenty years and with records for not less than five of the years in each decade.

Average yield of wheat, in bushels per acre, in States having records for more than twenty and less than forty years.

State or Territory.	First decade.	Second decade.	Third decade.	Fourth decade.
Utah		[a] 17.5	18.8	23.5
Nevada	[b] 21.1	[b] 17.3	19.2	26.0
Wyoming		[a] 17.4	[c] 21.0	23.0
Idaho		[a] 16.9	19.2	23.8
Colorado		[b] 19.2	19.0	24.6
North Dakota		[a] 14.1	[c] 14.0	12.3
Montana		[a] 17.5	20.8	26.7
New Mexico		[a] 13.2	15.6	20.0
Arizona		[a] 13.8	16.2	21.8
Washington		[a] 16.5	17.7	23.3

[a] Five years. [b] Seven years. [c] Six years.

The data here are so incomplete in comparison with what has been given, and the development of irrigation in many of these States has been so great a factor that the results will not be discussed. For some of the other States, notably Massachusetts, Connecticut, Rhode Island, South Dakota, Louisiana, and Florida, the data are so incomplete that no conclusion can be drawn.

From the foregoing analysis of the statistics that are available it is seen that there is no indication of a general decrease in productivity of our soils when planted to wheat. If any conclusion is to be drawn from the data, it must be that the productivity has increased. This applies equally to States and groups of States where the acreage has remained constant, where it has increased, and where it has decreased. It applies equally to States where commercial fertilizers have been used more or less freely and to States where the use of commercial fertilizers has not yet become general. It applies as well to the older soils of the Eastern and Southern States as to the newer soils of the Western States. The conclusion seems to be inevitable that the upward tendency observable is due to better and more intelligent methods of control. However much we may be impressed by the cases of failures which come to our personal knowledge, in the country as a whole the sum of successes counterbalance the failures rather better at present than in the past.

THE YIELD PER ACRE OF CORN IN THE UNITED STATES.

The average yield per acre of corn in the United States for the past forty years, from 1867 to 1906, as given by the Bureau of Statistics is 25.1 bushels. The figures representing the average yield for the four decades are 26.2, 25.1, 24.1, and 25.4.

Average yield per acre of corn in the United States from 1867 to 1906, by years and by decades.

1867–1876.	1877–1886.	1887–1896.	1897–1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
23.6	26.7	20.1	23.8
26.0	26.9	26.3	24.8
23.6	29.2	27.0	25.3
28.3	27.6	20.7	25.3
29.1	18.6	27.0	16.7
30.8	24.6	23.1	26.8
23.8	22.7	22.5	25.5
20.7	25.8	19.4	26.8
29.5	26.5	26.2	28.8
26.2	22.0	28.2	30.3
26.2	25.1	24.1	25.4

There has been a considerable increase in acreage, the total acreage for the four decades being 386,884,000, 634,089,000, 742,909,000, and 879,712,000. This change in the acreage, one of the factors upon which the average yield per acre is based, must be considered in drawing conclusions from the figures. The following diagram, however, is based on the yields regardless of changes in acreage:

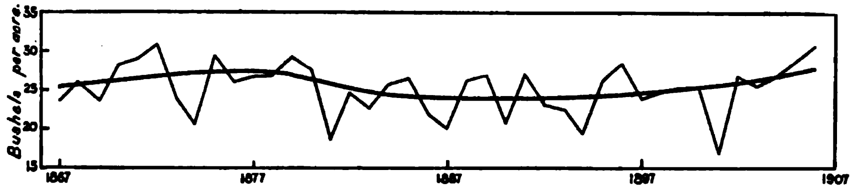

FIG. 14.—Average yield of corn in the United States from 1867 to 1906.

The medial line curves slightly downward during the middle of the period. It is somewhat doubtful if this apparent decrease is real, as there was evidently an adjustment of the department's estimates in 1881 to accord with the figures which were available from the records of the Tenth Census. Such adjustment was undoubtedly made for some of the States, but not for all, as will appear further on, and these adjustments affected the estimates for the United States. Allowing for such an adjustment the medial line of the diagram should be broken at 1880–81 and the two parts would then show a gradual and constant rise from each point of origin. That such an adjustment was made seems altogether likely from the following statement by the statistician of the department:[a]

> The abnormal extraordinary increase of recent years made it difficult to keep pace with advancing production, as is shown by the record for 1879, which is widely at variance with the census returns for that year. In other crops the difference is usually slight between the two records, but in the corn estimate it is evident that the department figures are quite too low.

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[a] Report of the Commissioner of Agriculture, 1881–82, p. 580.

It seems impossible after the lapse of nearly thirty years to determine with certainty what adjustments were made for the several States at any particular time in a system which from the very nature of its work should be adjusted from time to time as definite figures are established.

In most of the States there has been a decided increase in corn acreage. In only Maine and Rhode Island has there been a decided decrease in acreage. In New Hampshire, Vermont, Massachusetts, Connecticut, New York, Pennsylvania, and New Jersey there has been little change in acreage. In California there was an increase followed by a decrease in the last decade.

The following table gives the percentage of increase in the acreage of the twenty-four States showing a material increase from 1867 to 1906:

Percentage of increase in corn acreage from 1867 to 1906 in the several States where material increase has occurred.

State.	Percentage of increase.	State.	Percentage of increase.	State.	Percentage of increase.
Nebraska	2,500	Missouri	130	Kentucky	56
Kansas	700	*Average for United States*	127	Indiana	54
Texas	356	Michigan	124	Mississippi	50
Minnesota	469	Louisiana	121	Tennessee	49
Arkansas	190	Virginia	87	Alabama	46
Iowa	179	South Carolina	85	Illinois	36
Florida	153	North Carolina	75	Maryland	26
Wisconsin	152	Georgia	72	Ohio	21
West Virginia	133				

The following table gives the States for which forty consecutive years' records are furnished by the Bureau of Statistics (excepting California, which has thirty-nine years' record), arranged according to their average yields per acre:

Average yield of corn, in bushels per acre, for forty years, 1867–1906, by States.

State.	Yield.	State.	Yield.	State.	Yield.
New Hampshire	35.1	Illinois	30.2	Tennessee	22.0
Vermont	35.1	Rhode Island	30.1	Arkansas	20.0
Massachusetts	34.5	California	30.1	Texas	19.1
Pennsylvania	33.2	Minnesota	29.2	Virginia	19.0
New Jersey	33.2	Nebraska	28.7	Louisiana	16.7
Maine	32.9	Missouri	28.3	Mississippi	15.0
Ohio	32.9	Maryland	26.6	North Carolina	13.3
Connecticut	32.2	Kentucky	26.1	Alabama	13.1
Iowa	32.2	West Virginia	25.3	Georgia	11.0
Indiana	31.5	Kansas	25.1	Florida	9.8
Wisconsin	31.3	*Average for United States*	25.1	South Carolina	9.7
New York	30.8	Delaware	22.6		
Michigan	30.8				

There are twenty-three States in which the yield equals or exceeds the average yield of the United States and twelve States having a lower yield.

In looking over the crop records of a State or nation for a period of years one can not help being impressed with the wide fluctuations in yields from year to year, giving the diagram, when the points of observation are connected by straight lines, a saw-tooth appearance. This seems to be due principally to variations in rainfall. This fact is brought out in a striking way for the corn crop by J. Warren Smith, who says: [a]

> All cultivators of the soil recognize the important relation between precipitation and crop yield. Johnson [b] said in 1870: "It is a well-recognized fact that next to temperature the water supply is the most influential factor in the production of a crop."
>
> We believe that few people have any proper appreciation of the effect of an abundant water supply upon the ultimate yield of crops, although this subject is now receiving careful investigation. In a recent publication of the Department of Agriculture [c] describing an exhaustive investigation of many types of soils under many conditions of cultivation and wide range of yields it was found impossible to correlate the yields observed with the nutritive mineral elements in the soil or in the soil solution, which latter is the immediate source from which plants feed. From this it was concluded that on the average farm the great controlling factor in the yield (but not necessarily the quality) of crop is not the amount of plant food present, but a physical factor, the exact nature of which is yet to be determined, and this idea is made more definite by the further statement "that the actual quantity of water a soil can furnish the plant, irrespective of the percentage of water actually present in the soil, has probably a very important influence on the yield."
>
> It is self-evident that to have water furnished to the plant in any soil in sufficient quantities there must be an abundant supply available either through actual rainfall or through irrigation; so that, other things being equal, the results of the investigations of the Bureau of Soils seem to agree with the results found in practice, namely, heavy rainfall, large yields; light rainfall, small yields. And not only this, but, in a latitude and elevation favorable for the production of crops, precipitation has first place and temperature the second.
>
> It was with something of this thought in mind that the writer, assisted by Prof. William D. Gibbs, president of New Hampshire State College, began the preparation of the accompanying charts; yet neither was prepared for the remarkable confirmation of their theory or the close relation between the yield of corn and the precipitation in certain definite short periods during the growth of the crop.
>
> * * * Inasmuch as the greater portion of the corn produced in the United States is grown in the central part of the country, only Ohio, Indiana, Illinois, Iowa, Nebraska, Kansas, Missouri, and Kentucky are considered, both in the yield per acre and the precipitation.
>
> As the area of greatest corn production does not include all of Ohio, Kentucky, Kansas, and Nebraska, we probably should have considered only the western parts of Ohio and Kentucky and the eastern parts of Nebraska and Kansas for both yield and rainfall. * * *

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[a] Relation of Precipitation to Yield of Corn, J. Warren Smith, Section Director, Weather Bureau, Yearbook of the Department of Agriculture, p. 215, 1903.

[b] How Crops Feed, p. 216.

[c] Bulletin No. 22, Bureau of Soils, p. 63.

In the following chart the rainfall for June, July, and August is combined in the dotted line, giving the average total rainfall for those months over the eight States. The full line shows the yield.

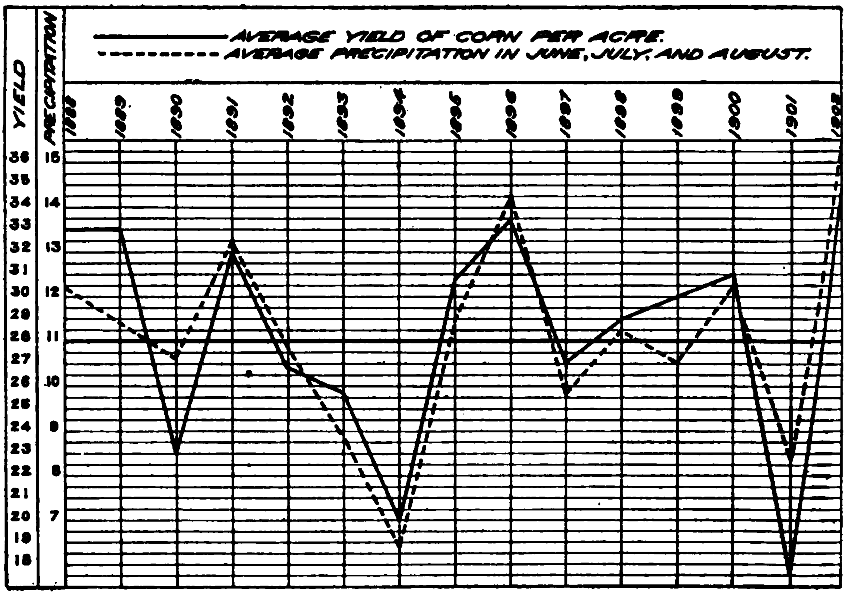

FIG. 15.—Precipitation for June, July, and August, and yield of corn per acre.

It is supposed to take from twenty to thirty years to establish a normal monthly temperature and longer than this to establish a reliable normal for rainfall.[a] As the variation in yield is of the same order as the variation in rainfall, we must not take too seriously slight variations or inequalities in average yields for periods of ten years but rather by generalization attempt to get at the trend of the change rather than at actual amounts of increase or decrease.

Of the six New England States, the acreage in Maine and Rhode Island has materially decreased, while indications are that the yield per acre has slightly increased. The acreage of the four other States has remained fairly constant, while the figures indicate a slight decrease in yield per acre in New Hampshire and Vermont, and a slight increase in Massachusetts and Connecticut. The differences, however, are so slight, as compared with the fluctuations within the decades that no safe conclusions can be drawn as to any change of productivity. Comparing the groups of States, as was done in the case of wheat, the total acreage for the four decades was 2,469,000, 2,627,000, 2,169,000, and 1,951,000, while the relative yields for the four decades may be expressed by the figures 32.6, 32.5, 34.7, and 34.4, indicating, if anything, a slight increase in productivity of the soils as measured by the yield per acre of corn.

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[a] A recent publication of the Weather Bureau, entitled "Summary of the Climatological Data for the United States by Sections: Section 1—Southern Texas," pp. 1, 2, contains the following statements:

"The period of observations, 1871 to 1907, inclusive, thirty-seven years, covers a sufficient length of time to warrant the assumption that the variations within which the several climatic elements are liable to fluctuate are embraced therein. * * *

"The tables of temperature, days with rain, average relative humidity, etc., generally cover periods of less duration than the precipitation data, but of sufficient length to construct dependable averages."

Average yield per acre of corn in Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
33.2	35.7	34.4	33.5
33.6	36.2	26.3	39.2
29.8	32.6	34.0	36.1
32.4	33.3	34.8	36.8
31.9	30.2	36.7	38.2
34.3	25.2	36.3	26.3
31.0	33.1	30.1	25.2
30.5	32.7	35.3	35.3
33.1	33.4	40.1	36.4
35.7	33.0	39.1	37.1
32.6	32.5	34.7	34.4

The figures representing the average yields for the several decades appear to fluctuate slightly, but the diagram shows this to be due to four or five exceptionally low yields, while the medial line shows an upward trend during the forty years for this group of States.

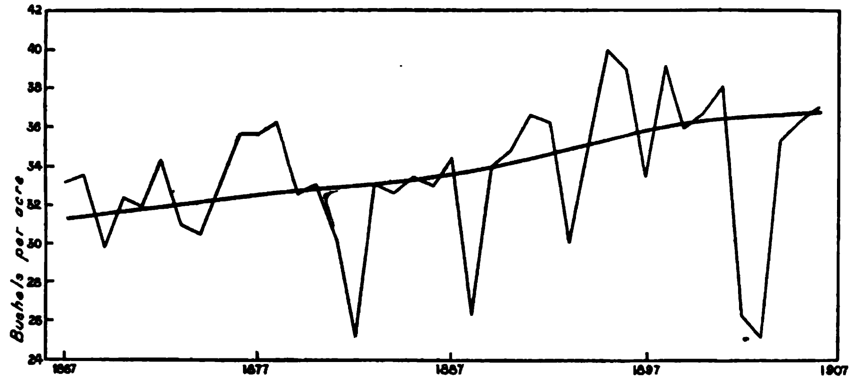

FIG. 16.—Average yield of corn in Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut from 1867 to 1906.

The acreage in New York, Pennsylvania, and New Jersey has varied but little in the forty years. The figures representing the average yield for the several decades—34.3, 31.4, 31.5, 33.2—indicate neither an increase nor a decrease in productivity.

Average yield per acre of corn in New York, New Jersey, and Pennsylvania from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
31.8	33.8	31.7	32.8
34.8	35.7	32.4	35.7
29.8	34.0	29.8	34.0
34.3	38.8	28.4	30.0
34.8	24.9	33.1	35.0
38.7	29.2	31.7	31.9
34.0	26.0	26.6	26.7
32.7	31.0	31.1	33.1
38.3	31.7	34.0	35.4
33.7	28.9	35.7	37.1
34.3	31.4	31.5	33.2

When the data is charted, however, it is seen that there is a decided break at the years 1880–81 when the census figures were available, and the only possible explanation is that the department's estimates were adjusted at that time in conformity with the facts determined by the census. The medial line of the diagram is seen to rise gradually but steadily from the two points of origin, indicating a gradual increase rather than decrease in productivity of the soils of these States, as was shown in the last group of States.

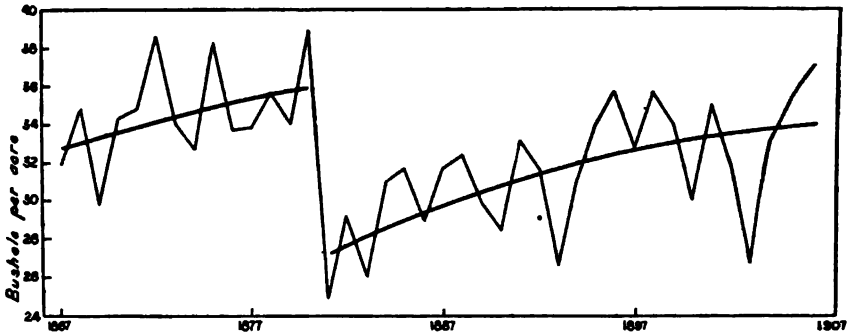

FIG. 17.—Average yield of corn in New York, New Jersey, and Pennsylvania from 1867 to 1906.

The acreage in corn in Maryland, Delaware, and Virginia has materially increased, the total acreage for the several decades being 16,145,000, 24,973,000, 28,038,000, and 26,243,000. The figures representing the average yield per acre—22.2, 21.3, 21, 27.1—show nothing definite regarding a change in productivity.

Average yield per acre of corn in Maryland, Delaware, and Virginia from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
21.9	23.2	21.5	26.7
24.0	22.0	19.1	26.0
17.9	25.5	18.0	24.7
22.5	29.7	19.5	22.0
22.7	17.9	22.4	28.8
21.3	21.3	18.2	27.5
19.8	18.5	22.6	26.0
19.5	18.5	21.3	29.0
26.0	18.7	22.1	30.2
26.3	17.7	25.2	29.8
22.2	21.3	21.0	27.1

The diagram, however, shows a very decided break at the period 1880–81, which is undoubtedly due, as in the case of the last group of States, to a readjustment of the department's estimates to accord with the findings of the Tenth Census. The two sections of the medial line each show a decided rise from the point of origin, indicating a decided increase in productivity for this group of States for the forty-year period.

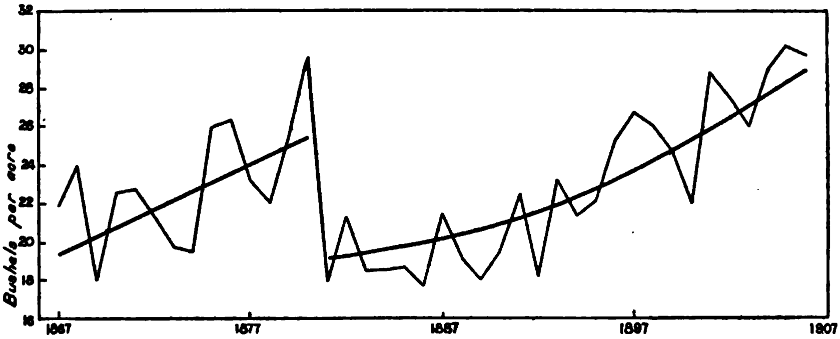

FIG. 18.—Average yield of corn in Maryland, Delaware, and Virginia from 1867 to 1906.

The total acreage in corn for the several decades for the group of States embracing North Carolina, South Carolina, Georgia, Florida, and Alabama, 66,993,000, 86,117,000, 102,619,000, 113,809,000, show a decided increase. The figures representing the average yield for the several decades, 12.2, 10.8, 11.4, 11.3, give little indication of a change in productivity.

Average yield per acre of corn in North Carolina, South Carolina, Georgia, Florida, and Alabama, from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
12.4	11.7	11.7	10.6
11.7	11.0	10.3	11.4
12.7	10.6	11.8	10.8
13.0	11.3	10.7	9.6
11.9	9.1	12.3	9.7
13.2	12.5	10.6	10.0
12.2	9.6	10.4	12.3
12.3	11.0	12.0	13.0
11.5	10.5	13.1	12.1
11.3	10.6	10.9	13.3
12.2	10.8	11.4	11.3

In this case the diagram brings out nothing more definitely than do the figures, and it is not evident that the productivity has changed materially one way or the other.

The total acreage for the several decades for the group of States embracing Ohio, Indiana, Illinois, Michigan, Wisconsin, and Minnesota is 126,441,000, 177,378,000, 162,838,000, and 193,646,000. The figures representing the average yields for the several decades, 31.9, 30.3, 28.9, 33.1, show definitely little as to any change in productivity.

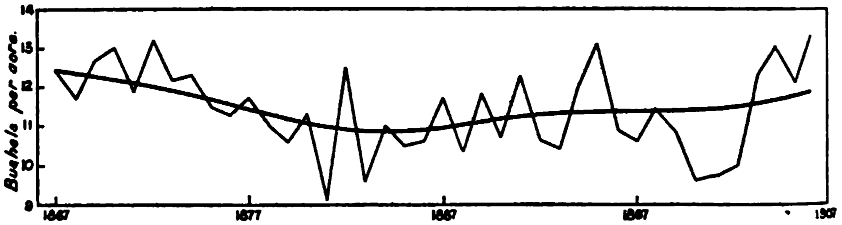

FIG. 19.—Average yield of corn in North Carolina, South Carolina, Georgia, Florida, and Alabama from 1867 to 1906.

Average yield per acre of corn in Ohio, Indiana, Illinois, Michigan, Wisconsin, and Minnesota from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
29.5	29.8	23.8	30.9
33.6	34.6	32.1	34.0
26.8	35.6	28.2	33.8
36.9	33.7	26.5	36.8
36.6	25.7	30.2	25.9
37.9	29.5	27.3	31.9
29.0	23.9	26.0	31.0
27.8	29.2	24.4	30.9
31.0	32.5	33.3	37.0
30.0	28.8	37.0	38.3
31.9	30.3	28.9	33.1

The diagram shows either a considerable depression in curvation of the medial line with a general trend upward, or, what is more likely, a readjustment of the department's estimates in 1881, which would give two sections of a nearly straight broken line with a decided upward slope. It is impossible to state at this time which of these two interpretations of the diagram is correct. Each of them, however, shows a marked tendency toward increased productivity; the one more than the other.

The average yield for Nebraska and Kansas for the several decades may be expressed by the figures 33.5, 33.2, 24.5, and 24.9. These two States show by far the greatest increase in corn acreage of any of the 35 States under consideration. The basis for the estimate of the average yield per acre in the last decade—namely, the acreage—was 700 per cent larger in Kansas and 2,500 per cent larger in Nebraska than in the first decade; yet we have in Nebraska the average yield of 32 bushels on 3,011,000 acres in the first decade to compare with the average yield of 27.8 bushels on 77,213,000 acres in the last decade and nearly as great a disparity in the case of Kansas. The combined acreage for the four decades is 12,625,000, 63,621,000, 110,130,000, and 154,177,000.

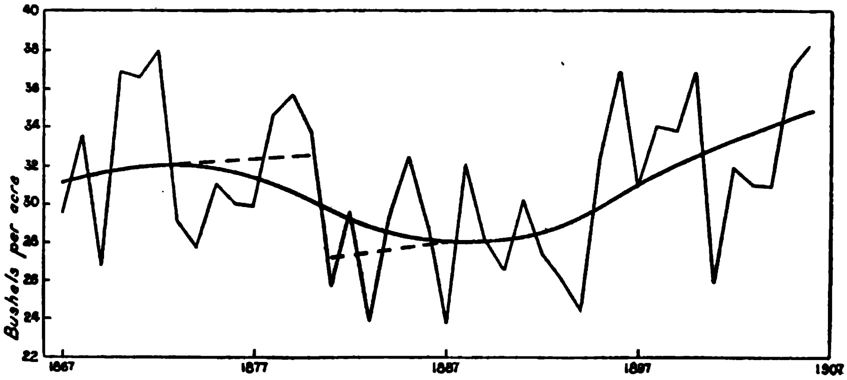

FIG. 20.—Average yield of corn in Ohio, Indiana, Illinois, Michigan, Wisconsin, and Minnesota from 1867 to 1906.

However, taking the original data as they stand, we find, in going back to the records for the individual State, three years of crop failure in Kansas in the third decade, the average yields being for 1887, 14.6 bushels; 1890, 15.6; and 1894, 11.2, the highest yield being in 1889, 35.3 bushels. In the last decade there were three years of very low yields—1897, 18 bushels; 1898, 16; and 1901, 7.8. The last five years of the last decade show four years well above the average for the forty years. Similarly, in the third decade, Nebraska shows a yield of only 6 bushels in 1890, while in the last decade are two very low yields and four out of the last five years show a considerably larger yield than the average for the forty years.

Average yield per acre of corn in Nebraska and Kansas, from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
37.5	37.2	19.3	24.0
20.4	37.9	30.9	18.5
45.3	37.0	35.9	27.5
28.9	30.2	16.8	22.5
40.7	22.8	30.9	10.9
38.1	34.3	26.3	31.1
37.0	36.3	23.2	25.8
10.2	37.3	8.6	26.8
40.0	34.5	20.2	30.2
36.7	24.6	32.7	24.9
33.5	33.2	24.5	24.9

The diagram shows a great depression covering the past twenty years. This may be due in part, but not entirely, to a readjustment of the Department's estimates in 1881. It is probably due in part to the westward extension of agriculture into the drier soils of the western parts of these States.

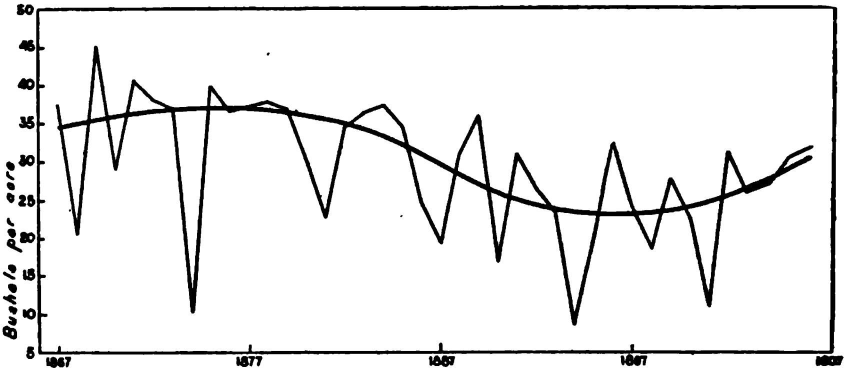

FIG. 21.—Average yield of corn in Kansas and Nebraska from 1867 to 1906.

The same general inequalities are shown in the statistics for the other crops reported upon for these two States by the Bureau of Statistics, with the possible exception of wheat, and while the facts can be explained only in part there is nothing that clearly indicates a positive change in productivity.

Adjoining Kansas and Nebraska on the east are the States of Iowa and Missouri, where there has likewise been a considerable increase in acreage, although not so large as in the first-named States. The total acreage of the two States for the four decades is 58,188,000, 117,138,000, 141,778,000, and 148,721,000. The average yields may be expressed by the figures 32, 29.7, 29.8, and 30.2.

Average yield per acre of corn in Iowa and Missouri from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
30.5	30.7	23.7	27.5
33.6	31.8	33.4	30.5
31.9	37.5	35.8	28.5
31.7	33.2	25.9	33.0
40.2	21.1	33.3	17.5
38.4	27.7	28.0	35.5
26.2	25.9	30.9	30.2
22.6	33.7	18.5	29.4
35.8	31.7	35.5	34.3
28.9	23.6	33.0	35.9
32.0	29.7	29.8	30.2

The diagram indicates that there was a slight adjustment of the department's estimates in 1881 as indicated by the broken lines, but assuming that the curve should stand as drawn, in either case there is a tendency toward increased production.

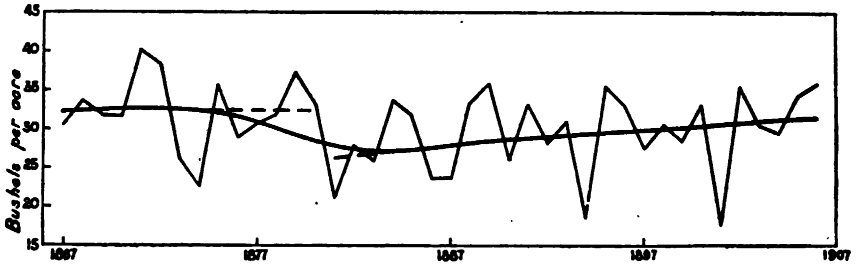

FIG. 22.—Average yield of corn in Iowa and Missouri from 1867 to 1906.

The total acreage in corn for the several decades for Mississippi, Louisiana, Texas, and Arkansas is 40,408,000, 71,225,000, 91,561,000, and 110,791,000. The figures representing the average yields for the several decades are 20.9, 17.5, 16.9, and 17.5.

Average yield per acre of corn in Mississippi, Louisiana, Texas, and Arkansas, from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
21.5	20.0	18.1	16.5
23.7	20.7	17.1	20.3
24.9	17.0	17.7	18.0
24.3	20.9	15.2	16.3
18.5	12.7	18.3	11.1
21.2	19.1	16.9	13.4
18.6	15.7	15.3	21.0
15.2	15.2	17.9	20.8
20.9	17.8	20.5	16.7
20.3	16.2	12.4	20.5
20.9	17.5	16.9	17.5

The diagram shows this inequality to be due to an apparent decline in productivity during the first half of the forty-year period. There has, however, evidently been a readjustment of the department's estimates in 1881 to accord with the census figures, and the medial line of the diagram should in this case be broken and continued in the direction of the broken lines. This would show in one interpretation of the diagram a general, but slight, tendency toward increased productivity over most of the period and by the other interpretation a more decided tendency toward increased productivity.

The total acreage in corn in California in the several decades is 326,006, 1,101,000, 1,127,000, and 562,000. The figures representing the average yield per acre for the several decades are 37.9, 28.7, 30.6, and 29.7.

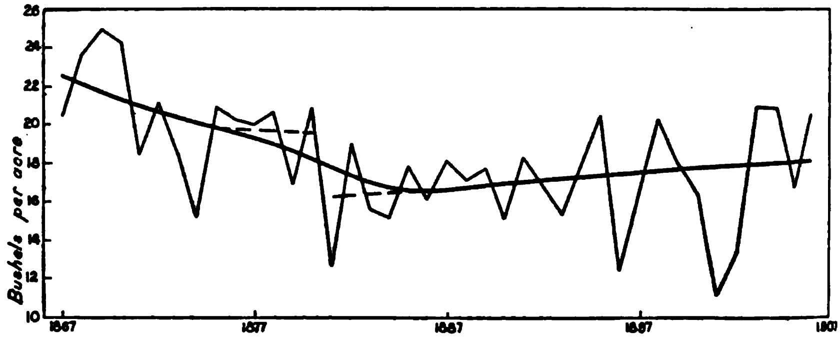

FIG. 23.—Average yield of corn in Mississippi, Louisiana, Texas, and Arkansas from 1867 to 1906.

Average yield per acre of corn in California from 1867 to 1906, by years and by decades.

1867-1876.	1877-1886.	1887-1896.	1897-1906.
Bushels.	*Bushels.*	*Bushels.*	*Bushels.*
....	30.0	30.0	31.5
45.0	34.5	27.8	26.0
41.4	28.0	28.2	27.0
35.6	32.0	27.5	25.0
38.0	27.2	34.5	31.0
35.0	28.3	30.3	30.5
41.0	24.5	37.1	30.7
36.2	30.0	19.3	28.6
36.3	24.7	34.5	32.0
33.0	27.2	37.0	34.9
37.9	28.7	30.6	29.7

The diagram shows a decided falling off in the first fifteen years, after which the general trend of the medial line is upward. The falling off appears to be real, as there is no appearance of a readjustment of the Department's estimates as there is in so many of the groups of States.

Summing up the evidence regarding the yield per acre of corn in the several States, it may be stated that there is no justification for the popular belief that the yield is decreasing in the United States or in any considerable portion of it, either on the soils of the older States in the East and South or on the soils of the newer States of the central or western part of the country; in the States which use commercial fertilizers or in those that do not. The acreage in corn in most of the States having increased considerably it is not possible to determine the effect of this increase on the yield per acre as was done in the case of wheat.

If any positive conclusion is to be drawn from the figures, it would have to be that the productivity of the soils of the United States and of the several States has increased during the past forty years as measured by the yield of corn.

With the full analysis of the data for the two important crops of wheat and corn, it seems unnecessary for the purpose of this report to discuss the data relating to oats, barley, rye, hay, buckwheat, potatoes, and cotton, especially as an inspection of the data furnished by the Bureau of Statistics on these crops shows the same general facts as are shown by wheat and corn and would add nothing material to this discussion. The only inference, therefore, which can be drawn from the statistics of crop production is that the productivity of the soils of the United States has not declined in the past forty years, but that, on the contrary, it has increased.

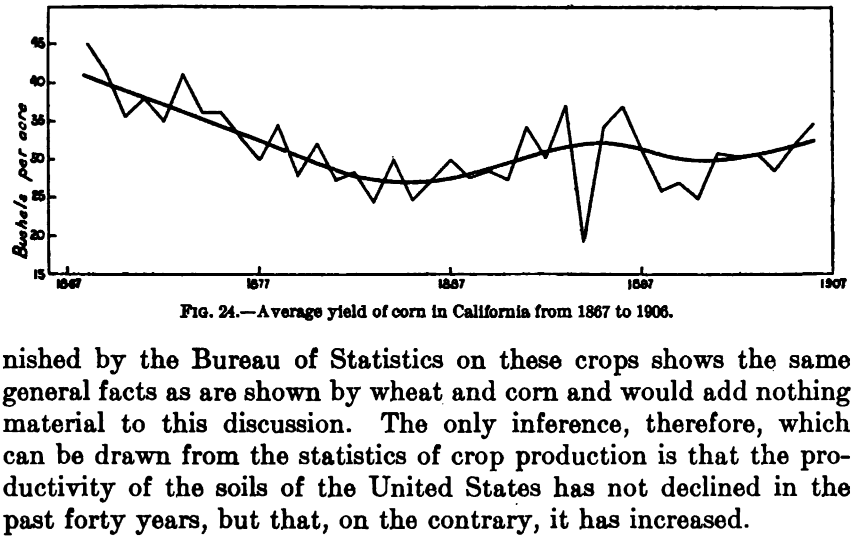

FIG. 24.—Average yield of corn in California from 1867 to 1906.

EVIDENCE PRESENTED BY THE YIELD OF CROPS ON INDIVIDUAL FARMS.

It may be argued that the statistics which have been presented for States do not represent the same soil or the same farms throughout the period, and this is undoubtedly true. But records of actual yields from the same farm for a long period of years are extremely rare. There are no such records for farms in the United States so far as the examined literature shows. Possibly if a thorough search were made a number of family records could be found of the annual yield of crops on individual farms which had remained in the same family for fifty to one hundred years or more and such data would be of much interest if made available.

Such investigations into old family records has recently been taken up in France and Germany with the most interesting and valuable results.

Kellermann has made a most exhaustive investigation and report upon the increase in crop production in Germany.[a] He gives the yields per acre of a large number of estates which have been handed down from father to son, some of the records going back to the middle of the sixteenth century. Three cases only will be given here, which show the general trend of the information he was able to gather.

Yield of cereals in Schmatzfeld (Germany).

[Reduced to bushels per acre.]

Year.	Wheat.	Rye.	Barley.	Oats.
1552-1557	12.5	13.2	14.2	14.8
1660	....	12.8	8.3	12.3
1670	14.6	17.2	16.1	17.4
1822	18.7	24.3	33.7	26.2
1825	18.1	20.0	28.1	32.5
1830	18.7	21.2	35.6	46.2
1840	25.6	30.0	31.6	45.5
1850	28.7	33.1	39.3	50.1
1860	35.3	39.3	32.9	62.9
1870	27.6	20.4	43.8	46.6
1886	37.9	28.9	43.2	66.6
1887-1896	40.0	29.6	47.6	59.7
1897-1904	45.1	34.0	50.4	69.1

The period from 1552 to 1557, apparently the average for those years, gives a yield of wheat of 12.5 bushels per acre; in 1670 there is a record of 14.6 bushels; in 1822 of 18.7 bushels; in 1825 of 18.1 bushels; in 1840 of 25.6 bushels; in 1850 of 28.7 bushels; in 1860 of 35.3 bushels; in 1897 of 45.1 bushels; an increase in those three hundred years from 12.5 bushels in 1552 to 45.1 bushels in 1897–1904, the record showing a regular increase with a few fluctuations which are probably due to seasonal conditions.

Rye has increased during the same time from 13.2 bushels in 1552 and 12.8 bushels in 1660 to 30 bushels in 1840 and 34 bushels in 1897.

Barley has increased from 14.2 bushels in 1552 or 8 bushels in 1660 to 16.1 bushels in 1670, and finally to 50.4 bushels in 1897.

Oats have increased from 14.8 bushels in 1552–1557, the first record, to 69.1 bushels in 1897–1904, which is the last record.

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[a] Landw. Jahrb. 35, 289 (1906).

Yield of cereal crops on Rittergut Trebsen, near Leipzic.

[Reduced to bushels per acre.]

Year.	Wheat.	Rye.	Barley.	Oats.
1756-1765	26.41	15.91	14.25	23.03
1766-1775	13.25	12.33	21.71	23.48
1776-1785	16.63	14.47	20.44	23.45
1786-1795	13.98	13.67	16.77	19.16
1796-1800	13.89	15.36	15.16	17.90
1814-1816	15.28	15.68	25.41	25.72
1820-1822	16.90	19.14	18.28	26.36
1825-1834	21.04	21.63	30.19	31.83
1835-1844	33.40	27.92	36.66	46.54
1845-1849	25.51	28.75	....	56.25
1883-1892	27.03	23.06	30.95	44.64
1893-1894	29.85	28.36	30.95	54.74
1895-1899	35.85	30.45	35.39	51.15
1900-1904	36.14	32.52	43.23	57.80

From this estate apparently more nearly continuous records are given in five and ten year periods from 1756 to 1904. The average yield of wheat in the first period of which we have a record, 1756–1765, is 26 bushels; in the next period, 1766–1775, it is 13 bushels; and from that time a gradual increase up to 1900–1904, when it was 36 bushels. Rye increases similarly by regular steps from 15.91 bushels to 32.52 bushels; barley from 14.25 bushels to 43.23 bushels; oats from 23.03 bushels to 57.80 bushels.

Yield of cereals on Gut I, of Conrad.

[Reduced to bushels per acre.]

Year.	Wheat.	Rye.	Barley.	Oats.
1800-1810	21.15	14.64	19.80	17.22
1810-1820	20.02	11.76	20.92	13.44
1820-1830	23.25	17.76	21.29	14.84
1830-1840	18.82	15.04	16.37	13.86
1840-1850	23.10	19.84	20.83	27.58
1850-1855	26.40	23.12	32.75	33.46
1855-1860	25.27	24.16	27.71	34.44
1860-1865	29.77	30.48	37.85	44.52
1865-1870	27.45	26.48	36.17	55.72
1870-1875	29.92	28.32	35.71	51.38
1875-1880	28.12	24.32	29.38	39.48
1880-1885	25.57	25.12	36.45	45.08
1885-1894	35.70	29.52	41.06	43.96

On this estate from 1800 to 1894 in ten-year averages wheat increased from 21.15 to 35.70 bushels, rye from 14.64 to 29.52, barley from 19.8 to 41.06, and oats from 17.22 to 43.96.

Kellermann throughout cites many well-known authorities and refers to many sources of information, and concludes his article with this remarkable statement:

> If we now make a brief survey of the results obtained in the foregoing, we must affirm that the development of the yields of cultivated soil since the beginning of the past century presents a very pleasing picture, not only that agriculture, by absolute addition to the acreage of 30 to 35 per cent and decrease in fallow from 33 to 4½ per cent,

has tried to meet the growing needs of the nation for food, but above all that it has shown how to gain from the soil gradually 2½ times as much per unit of surface as formerly.

The same facts have been brought out by Steinbrück,[a] who cites many cases of individual farms from records going back for one hundred years or more.

EVIDENCE PRESENTED BY THE CHEMICAL COMPOSITION OF THE SOILS OF THE UNITED STATES AS COMPARED WITH THOSE OF EUROPE.

The soils of the countries of northern and middle Europe are to-day producing from two to three times as large yields of the staple farm crops as the soils of the Northern and Middle States of the United States. They are, therefore, removing from the soil more of the mineral plant-food constituents. The soils are older agriculturally in that the countries have been settled for one thousand to two thousand years longer for agricultural pursuits than the United States. The soils as a whole were, no doubt, similar originally in composition, as they are derived from the same class of rock materials. If, as some suppose, there is danger of permanent loss of fertility of our soils through loss of mineral plant-food constituents or any one essential constituent through the removal of our very moderate crops for one hundred or two hundred or even for one thousand years, the cropping records of European soils would be expected to have resulted in some significant difference in lower content of mineral plant-food constituents at the present time as compared with the newer agricultural soils of the United States.

For the purpose of such a comparison all analyses of soils by the acid digestion method, the results of which are available to us in the literature of the past eighteen years, have been compiled and are presented in the following tables so far as they pertain to the soils of Great Britain, Ireland, Germany, France, and the United States. It is in these countries where the most active work has been done and about which the most results have been published. There have been found and are presented in this bulletin the results of the analyses of 1,857 samples of soil from all parts of the United States, 286 samples from Great Britain and Ireland, 1,550 samples from France, and 449 samples from Germany. This makes a total of 4,142 analyses available for comparison.

So far as it has been possible to determine from the description of the analytical work all of the results used in this bulletin have been obtained from recognized methods of "acid digestion" with concentrated acid, and only the results pertaining to the top soil have been taken; the results pertaining to the subsoils having been rejected. This has been done to make the data strictly comparable.

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[a] Der Boden und die landwirtschaftlichen Verhältnisse des Preussischen Staates, vol. 7, p. 799 (1906), edited by August Meitzen.

It will be remembered that rocks vary greatly in their ultimate chemical composition accordingly as one or more of the common minerals predominate to give the essential character to the rock. Soils vary in ultimate chemical composition and, according to the mode of their formation, soils are generally more complicated than the rocks with respect to the minerals they contain. It is as difficult, therefore, to intelligently compare soils from their chemical composition, unless the physical characteristics are known, as it would be to compare or identify rocks from chemical data alone. As soil classification and soil surveying are new and not on an international basis, it is impossible to compare soils from different countries in any classified or systematic way from the data given in connection with the analyses.

Johnson wrote in 1869:[a]

> Notwithstanding an immense amount of labor has been expended in studying the composition of soils, and chiefly in ascertaining what and how much, acids dissolve from them, we have, unfortunately, very few results in the way of general principles that are of application, either to a scientific or a practical purpose. In a number of special cases, however, these investigations have proved exceedingly instructive and useful.

This applies now to the ordinary chemical analyses of soils as well as it did forty years ago.

The chemical composition of soils varies so greatly without any obvious law of general relationship to crop production that averages mean little or nothing and the figures are given without any attempt at averaging. The average amount of potash in all soils reported upon would probably be not far from 0.3 per cent. The extreme amounts reported in the following tables for all countries are 0.003 to 11.37 per cent. The average amount of phosphoric acid in all soils reported would probably be not far from 0.16 per cent. The extremes given in the following tables are 0.003 to 7.14 per cent. The extremes for lime are 0.002 to 94.7 per cent. The extremes for magnesia are 0.001 to 16.97 per cent.

Too much importance should not be paid to moderate differences in composition, as soils are liable to vary greatly in the same field. An excellent illustration of this is given in the results from St. Viaud, France; 73 samples were taken from a field of approximately 250 hectares (617 acres), of which the separate analyses are given us as shown in the following table.

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[a] Samuel W. Johnson, "How Crops Feed," p. 331.

Composition of 73 samples of soil taken from a field of about 617 acres in St. Viaud, France.

Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
....	0.07	0.03	0.16	0.13	....	0.18	0.06	0.08	0.07
....	.21	.09	.17	.15	....	.20	.06	.20	.09
....	.17	.04	.29	27	....	.18	.08	.12	.51
....	.14	.04	.26	.16	....	.12	.04	.11	.72
....	.12	.06	.16	.12	....	.15	.07	.21	.76
....	.23	.08	.13	.21	....	.10	.06	.15	.54
....	.21	.06	.10	.26	....	.11	.05	.12	.45
....	.09	.06	.15	.06	....	.15	.06	.27	.39
....	.17	.04	.16	.19	....	.20	.06	.12	.20
....	.20	.09	.13	.14	....	.14	.08	.22	.17
....	.24	.03	.35	.60	....	.12	.04	.06	.27
....	.12	.06	.32	.23	....	.25	.08	.09	.20
....	.14	.06	.18	.12	....	.12	.04	.05	.04
....	.22	.08	.18	.31	....	.18	.07	.21	.36
....	.19	.07	.12	.30	....	.20	.08	.10	.25
....	.16	.07	.16	.24	....	.22	.06	.16	.34
....	.21	.06	.18	.56	....	.12	.07	.09	.21
....	.17	.05	.47	.37	....	.20	.06	.10	.12
....	.10	.09	.16	.44	....	.22	.09	.18	.37
....	.14	.05	.30	.23	....	.25	.06	.15	.31
....	.14	.04	.24	.20	....	.25	.03	.17	.51
....	.15	.06	.08	.14	....	.24	.07	.12	.11
....	.21	.05	.30	.17	....	.22	.05	.09	.05
....	.15	.06	.15	.31	....	.23	.07	.07	.09
....	.10	.05	.18	.24	....	.21	.05	.09	.20
....	.16	.06	.27	.33	....	.22	.07	.27	.10
....	.12	.04	.14	.18	....	.15	.06	.10	.12
....	.18	.06	.11	.26	....	.12	.05	.20	.15
....	.15	.08	.22	.15	....	.13	.06	.19	.17
....	.10	.07	.39	.23	....	.10	.04	.47	.13
....	.17	.08	.18	.25	....	.14	.05	.13	.10
....	.15	.09	.33	.34	....	.18	.06	.11	.09
....	.12	.04	.12	.38	....	.17	.05	.38	.53
....	.11	.06	.12	.40	....	.51	.04	.17	.12
....	.20	.06	.10	.12	....	.16	.04	.18	.10
....	.09	.04	.07	.03	....	.15	.04	.16	.09
....	.10	.10	.06	.04					

In this field the potash varies from 0.07 to 0.51 per cent, phosphoric acid from 0.03 to 0.10 per cent, lime from 0.05 to 0.47 per cent, and magnesia from 0.03 to 0.60 per cent. This range in composition in this single field would cover most of the 1,565 samples reported from France; so that it would appear that there is no significant difference in composition with respect to these four mineral plant-food constituents in most of the soils of France which have been examined and reported upon.

Another reason why too much consideration should not be given to slight differences in composition is the unavoidable error of analysis. For a number of years it has been the practice of the referee on soils of the Association of Official Agricultural Chemists to submit samples of soil to various analysts for examination. These samples are thoroughly prepared by grinding, sifting, and mixing and careful subsampling to insure thorough uniformity in the samples which go to the different individuals. The method of analysis is explicitly prescribed so as to insure, as far as possible, uniformity in results. The following tables of results show the agreement:[a]

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[a] Bulletin No. 43, Bureau of Chemistry (1894), p. 33.

Variations in results of analyses of the same sample of soil by eight analysts.

[Provisional method: Thirty-six hours' digestion.]

Analyst.	K_2O.	Na_2O.	P_2O_5.	CaO.	MgO.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
A			0.429		
B	0.397	0.76	.480	0.585	0.519
C	.470	.155	.486	.521	.407
D[a]	.275	.280	.580	.360	.360
D[b]	.340	.140	.560	.410	.390
D[c]	.450	.140	.530	.430	.400
E[d]	.330	.125	.600	.430	.375
F	.49		.16	.60	
G	.44		.48		
H	.48		.47		

[a] Digestion in Snyder flask.
[b] In platinum flask and condenser.
[c] In platinum bottle, stoppered.
[d] Reported as dried at 110° C., figured to original soil by reporter.

The extreme variation here representing the possible limit of error has been: For potash 0.2 per cent, for phosphoric acid 0.44 per cent, for lime 0.24 per cent, and for magnesia 0.16 per cent.

Variations in results by eight analysts—phosphoric acid and potash calculated as per cent of the dried fine earth.[a]

[Official method: Ten hours' digestion in HCl of 1.115 sp. gr.]

Analyst.	K_2O. Sample No. —				P_2O_5. Sample No. —			
	1.	2.	3.	4.	1.	2.	3.	4.
A	0.359	0.154			0.447	0.268	0.409	0.230
B					.420	.210	.462	.244
C	.345	.112	0.380	0.04	.430	.117	.449	.095
D	.354	.235	.396	.225	.324	.201	.421	.267
E	.260				.510			
F[b]	.373	.179	.365	.175	.451	.172	.396	.193
F[c]					.412	.185	.383	.190
G	.210	.130	.220	.100	.460	.210	.500	.220
H	.304	.125	.286	.158	.425	.163	.422	.176

[a] Bulletin No. 47, Bureau of Chemistry (1896), p. 36. [b] Gravimetric. [c] Volumetric.

The extreme variation here has been for the various soils; For potash, 0.16, 0.12, 0.18, and 0.18 per cent, respectively; for phosphoric acid 0.19, 0.15, 0.12, and 0.15 per cent, respectively.

Variations in results by nine analysts—phosphorus soluble in fifth-normal nitric acid.[a]

[Parts per million in dry soil.]

Analyst.	No. 1.	No. 2.	No. 3.	No. 4.	Analyst.	No. 1.	No. 2.	No. 3.	No. 4.
A[b]	15.0	8.0	5.0	158.0	C	14.0	7.7	3.1	163.4
A	22.0	15.0	10.0	175.0	D	10.6	5.7	3.6	145.6
A[c]	18.0	10.0	5.7	158.0	D		5.6		
A	18.0	11.0	6.0	158.0	E	16.7	9.7	6.4	157.1
A[d]	14.4	7.4	4.4	165.5	F	31.7	15.2	25.5	167.4
A	14.0	7.4	4.8	162.0	G	14.4	7.8	4.8	165.4
B	13.4	5.8	3.6	155.5	G	14.6	7.8	4.8	166.0
B	12.9	6.1	2.5	154.5					

[a] Bulletin No. 105, Bureau of Chemistry (1907), p. 144.
[b] Work done according to directions sent out.
[c] Baking of residual omitted.
[d] Baking omitted and phosphorus determined by Kentucky method.

Variations in results by five analysts—potassium soluble in fifth-normal nitric acid by official method.[a]

[Parts per million in dry soil.]

Analyst.	No. 1.	No. 2.	No. 3.	No. 4.	Analyst.	No. 1.	No. 2.	No. 3.	No. 4.
A........	99.2	130.0	141.7	236.0	D........	89.3	107.9	120.8	189.1
A........	88.7	135.9	139.8	233.1	E........	91.3	136.0	142.5	244.9
B........	113.0	128.0	188.0	276.0	E........	96.1	133.8	139.8	249.9
C........	95.5	127.9	135.5	234.4					

[a] Bulletin No. 105, Bureau of Chemistry (1907), p. 144.

The determinations in the above tables being expressed in parts per million instead of in per cent can not be directly compared with the first two tables, but it is seen that the proportional variation is about the same.

The aggregate area of the three countries selected for a comparison of the soils with those of the United States is but a relatively small part of the continent of Europe. The total area of Europe is estimated at 3,550,000 square miles, according to Rohrbach, and 3,760,000, according to Wagner-Supan; of continental United States at 2,974,159 (land area) square miles. The area in square miles of the European countries selected for a comparison of the chemical composition of the soils with those of the United States covers only about one-sixth of the continent. The areas, as given in the Statesman's Yearbook, are as follows:

	Square miles.
Great Britain and Ireland:	
England	50,848
Wales	7,467
Scotland	30,405
Ireland	32,360
	121,080
Germany	208,780
France	207,054

The land area of some of our own States with which these figures are comparable are:

	Square miles.
Texas	262,398
California	156,092
Minnesota	80,858
Missouri	68,727
Illinois	56,002
Alabama	51,279
Florida	54,861
New York	47,654
Pennsylvania	44,832

THE CHEMICAL COMPOSITION OF THE SOILS OF THE UNITED STATES.

The following table contains the results of all the analyses made in the United States by the "acid digestion" method during the past eighteen years, so far as they have been found in the literature. A summary of the findings is given immediately following the table:

Chemical composition of the soils of the United States.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
California[a]	1	0.555	0.230	0.955	1.052
Illinois	3	.161	.066	.210	.247
	5	.525	.106	.610	.643
Kansas	7	.643	.089	.575	.501
Indiana	9	.496	.166	.465	.450
Massachusetts	12	.153	.144	.525	.558
Michigan	14	.118	.064	.490	.275
Missouri	16	.272	.121	.405	.550
Montana	18	.731	.185	.870	.907
New York	19	.321	.189	.250	.518
South Dakota	22	.390	.153	.665	.628
Texas	25	.095	.032	.175	.162
Wisconsin	27	.230	.125	.405	.412
Illinois	35	.580	.085	.520	.886
Iowa	39	.337	.137	.790	.585
New York	51	.351	.156	.140	.585
California	63	.594	.163	1.535	1.726
	65	.508	.117	.900	1.542
Illinois	69	.156	.070	.230	.218
	70	.479	.185	1.455	.989
Indiana	73	.384	.105	.370	.450
Iowa	74	.365	.093	1.185	.662
Kansas	76	.766	.128	.675	.615
Michigan	80	.134	.066	.405	.281
Montana	84	.747	.176	.970	1.105
New York	85	.246	.202	.125	.549
South Dakota	87	.365	.147	.710	.585
Texas	89	.053	.035	.150	.104
Wisconsin	90	.295	.163	.535	.457
Washington:[b]					
Yakima County	17	1.07	.13	2.00	1.34
Kittitas County	37	.70	.18	2.08	1.47
Oregon,[b] Morrow County	79	.89	.18	1.37	1.08
Alabama[c]	....	.15	.017	.051	.01
Butler County	1129	.182	.029	.275	.293
Talladega County	1131	.903	.150	.289	.633
Pike County	1133	.149	.032	.039	.062
Arizona:[d]					
Glendale	3	.955	.244	2.213	2.535
	4	.528	.148	3.028	1.991
	5	.777	.220	2.721	2.441
	6	.472	.140	2.883	2.025
Granite Mountains	11	.671	.059	2.068	1.391
Orangewood	10	.630	.112	2.453	1.668
Tempe	17	.783	.080	1.336	1.317
	14	.593	.058	1.354	1.188
Glendale	1	1.025	.053	.981	1.764
	2	.563	.122	1.282	1.356
Orangewood	9	.860	.106	1.284	1.713
Glendale	7	.818	.207	2.703	2.326
Mesa	19	1.959	.227	1.240	2.102
	8	.970	.210	2.419	2.541
Tempe	16	1.094	.179	5.711	3.086
	18	1.045	.147	2.611	2.013
	15	.683	.149	3.513	1.466
Glendale	12	.777	.053	4.205	1.564
	13	.686	.045	2.854	1.447
Casa Grande	20	.534	.031	.579	.775
California, Needles[d]	21	.928	.185	6.427	....

[a] This and following samples, to and including number 90, analyzed by Moore, Jour. Am. Chem. Soc. *24*, 85 (1902).

[b] Hilgard, Weather Bureau Bul. No. 3, p. 18 (1892).

[c] Bul. 3, n. s. Alabama Agr. Expt. Sta., No. 3, p. 13 (1889).

[d] Bul. 28, Arizona Agr. Expt. Sta., pp. 77-92 (1898).

Chemical composition of the soils of the United States—**Continued.**

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
California: [a]		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Amador County	1291	0.64	0.05	0.20	0.18
	1294	.26	.07	.17	.16
	1115	.53	.05	.50	.30
	1113	1.48	.05	.60	2.21
Butte County	1139	.26	.07	6.10	1.23
Shasta County	1028	.273	.041	.113	.306
Merced County	1192	.26	.03	.49	.33
Fresno County	1061	.418	.028	1.417	1.955
	1065	.29	.02	1.02	.63
	1055	.82	.07	1.14	1.58
	1189	1.32	.06	.99	1.54
	1190	.67	.16	1.31	1.74
	1191	1.01	.08	1.10	1.28
Alameda County	1029	.28	.70	8.21	.43
Santa Clara County	999	.31	.11	1.39	16.97
Napa County	1075	1.48	.08	.30	1.43
	1077	.67	.08	2.49	10.77
Sacramento County	880	.65	.08	.71	1.71
Contra Costa County	1230	.24	.06	.66	.34
San Bernardino County	809	.79	.11	1.51	1.24
	812	.97	.05	1.65	1.68
	1406	.87	.14	1.57	1.33
	1536	.73	.07	1.58	1.85
	1537	.69	.03	1.71	1.78
	1248	.74	.09	1.11	1.40
	1251	1.17	.11	1.19	1.29
	1246	.68	.12	1.15	1.30
	1253	1.17	.11	.96	1.27
San Diego County	1238	.64	.06	1.06	....
	1092	1.42	.35	2.20	2.09
Arizona: [a]					
Near Yuma	506	1.18	.13	8.67	2.97
Gila River Valley	1195	.66	.23	6.26	.66
California: [b]					
Sutter County	1645	.74	.24	2.06	2.13
Tehama County	1636	.50	.26	.81	1.14
Sacramento County	1698	.49	.20	1.45	.94
	1699	.62	.11	1.55	.94
Kern County	1466	1.04	.22	1.29	1.24
Sonoma County	1647	.99	.16	.90	1.97
Napa County	1655	1.28	.09	.54	.91
Alameda County	1679	.73	.19	1.15	1.08
San Luis Obispo County	1693	.51	.29	1.04	.34
San Benito County	1704	.45	.16	1.16	2.09
Ventura County	1714	.47	.21	.67	.57
Riverside County	1758	1.37	.23	4.23	3.80
	1759	.84	.12	2.19	2.32
	1760	1.16	.28	8.00	5.69
	1761	1.01	.22	13.94	6.16
Orange County	1016	.80	.08	2.04	1.92
Tulare County	1159	1.20	.10	1.86	1.81
	1157	1.31	.14	1.70	1.96
	1163	1.24	.09	3.06	2.71
East Highlands	1984	.98	.13	.96	1.42
Riverside	1406	.87	.14	1.57	1.33
Corona	....	1.17	.11	1.19	1.29
Wheatland	2403	.42	.20	.72	1.45
	2405	.42	.14	.97	1.83
	2408	.65	.21	.83	1.50
	2411	.23	.09	.25	.29
Salton Basin	2324	.76	.23	4.35	1.24
	2325	.74	.22	3.75	1.68
Berkeley	2430	.33	.07	.76	.76
Colorado: [c]					
Arkansas Valley	1	.23	.23	2.80	.97
	2	.27	.22	1.28	.97
	3	.59	.21	3.69	1.61
Yuma	4	.39	.14	1.46	.69
Fort Collins	5	.56	.16	3.58	.73
	6	.62	.15	2.17	1.00
	7	.41	.21	.70	.85
	8	.66	.29	.91	.69

[a] Ann. Rep. Cal. Agr. Expt. Sta., 1890, pp. 23-50.

[b] Results for this and the following samples to and inclusive of 2411 from Ann. Rep. Cal. Agr. Expt. Sta., 1899-1901, 1893-4, 1894-5, 1895-1907; Nos. 2324 to 2425, from Bul. 140, Cal. Agr. Expt. Sta. (1902); No. 2430 from Bul. 143, Cal. Agr. Expt. Sta. (1907).

[c] Buls. 9 and 10, Colo. Agr. Expt. Sta. (1890).

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O.)	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
Colorado—Continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
San Luis	9	0.41	0.23	0.67	0.54
	10	.27	.23	.81	.56
	11	.14	.14	.68	.67
Fort Collins		.41	.21	.70	.85
Florida:[a]					
Lake City	D		.02	.03	.02
	E		.70	.34	.13
			.07	.06	.03
			.02	.03	.05
Auburndale	16		.01	.10	.03
	7		.005	.007	.001
	18		.005	.008	.003
Tobacco soil	1	.018	.053	.130	.008
Tobacco soil (Cuban)	2	.160	1.60	7.60	.17
Pineapple soil		.006	.012	.000	.009
Orange soil		.014	.018	.034	.022
Cotton soil		.010	.032	Trace.	.020
Indiana:[b]					
Newton County		.47	.17		
		.23	.22		
Hendricks County		.680	.284		
		.181	.222		
Fountain County		.428	.123		
		.281	.154		
Delaware County		.32	1.01		
		.35	.46		
		.21	.16		
		.22	.36		
Kentucky:[c]					
Hodgenville	2003	.090	.172	.080	
Lagrange	2004	.190	.182	.190	
Beard	2130	.532	.096	.198	
	2131	.515	.080	.175	
Newport	2276	Trace.	.592		
Lexington	2501	.510	.537	.605	.503
	2502	.480	.445	.425	.393
Casky	2600	.310	.117		
Meade	6039	.178	.030		
	6040	.249	.040		
	6041	.204	.055		
	6043	.214	.060		
	6044	.308	.039		
Shelbyville	7716	.096	.27	.26	
Scottsville, Allen County	7720	.120	.015	.120	
Lincoln County	7885	.169	.064		
Logan County	8457	.397	.073		
Lewis County	8599	.251	.038		
Boone County	8810	.223	.090		
	8847	.234	.090		
Marshall County	8856	.308	.038		
	8857	.411	.042		
Kenton County	8897	.357	.094		
Breckenridge County	9541	.26	.07		
	9802	.160	.158		
Casey County	9800	.159	.069		
Fayette County	10249	.318	.475	.520	.320
Henry County	9798	.264	.123		
Hopkins County	9623	.145	.052		
	9624	.165	.072		
Livingston County	10493	.471	.263		
	10494	.505	.230		
	10495	.475	.170		
	10496	.214	.030		
Pulaski County	9766	.141	.030		
Grayson County	11067	.148	.063		
Meade and Hardin counties	11068	.134	.074		
Henderson County	11188	.273	.077		
Hickman County	11170	.224	.080		
	11171	.440	.118		
Hopkins County	11174	.162	.064		
Lincoln County	10735	.160	.041		
Logan County	11119	.220	.155		
Boone County	14398	.206	.076		

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[a] Bul. 5, Fla. Agr. Expt. Sta. (1899); Bul. 6 (1889); Bul. 19 (1893); Bul. 87 (1906).

[b] Bul. 95, Ind. Agr. Expt. Sta., pp. 25–29 (1903).

[c] This and following samples to and including No. 8599, Rep. Ky. Agr. Expt. Sta., 1892, 1893, 1894, 1899, 1901, 1902, 1903; Nos. 14398 to 14604, Bul. 126, Ky. Agr. Expt. Sta.

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
Kentucky—Continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Boyd County	14401	0.130	0.064	....	....
Casey County	14407	.542	.058	....	....
Clark County	14411	.710	.377	0.500	0.480
	14412	.732	.455	.600	.500
	14610	.549	1.335	.725	.280
	14613	.646	1.755	1.100	.240
	14654	.375	.855	.712	.400
	14618	.638	1.695	1.175	.320
	14648	.455	.485	.739	.420
	14616	.407	.710	.350	.200
	14650	.407	.512	.607	.520
	14652	.401	.755	.739	.480
Fayette County	14408	.360	.132	....	....
	14409	.576	.182	....	....
	14498	.417	.524	....	....
	14577	.582	.302	....	....
	14490	.405	.450	.400	.400
	14491	.400	.444	.475	.520
	14492	.380	.390	.400	.400
	14493	.410	.562	.600	.480
	14494	.407	.590	.650	.480
	14495	.452	.770	.725	.420
	14482	.435	.490	....	....
	14483	.437	.474	....	....
	14484	.337	.392	.300	.220
	14485	.347	.322	.350	.340
Henry County	14399	.278	.356	....	....
	14477	.300	.274	....	....
Knox County	14633	.125	.042	....	....
Muhlenberg County	14636	.483	.120	....	....
Ohio County	14410	.262	.040	.200	.300
Pendleton County	14400	.202	.096	....	....
Rockcastle County	14480	.180	.038	....	....
	14499	.350	.054	....	....
Warren County	14509	.430	.070	....	....
	14592	.188	.046	....	....
	14593	.256	.055	....	....
	14594	.307	.050	....	....
	14595	.280	.025	....	....
Woodford County	14513	.340	.428	....	....
	14606	.472	.625	....	....
	14604	.548	1.385	1.725	.240
Louisiana[a]	1a	.100	.064	.170	.114
	2a	.120	.112	.060	.021
Maine,[b] Scarboro	cccxcv	.14	.17	....	....
Maryland:[c]					
Washington County	133	.55	.50	.56	....
	134	.35	.32	.56	....
	463	.45	.24	.31	....
West Virginia,[c] Martinsburg	465	.43	.28	.12	....
Maryland,[c] Washington County	466	.22	.20	.56	....
	467	.32	.19	.31	....
Michigan:[d]					
Lenawee County	1	1.84	.40	1.98	1.43
	2	2.05	.41	2.10	1.59
Washtenaw County	3	1.18	.40	1.28	.86
Cass County	4	1.18	.44	2.02	.66
	5	1.10	.33	1.38	.56
Shiawassee County	6	1.85	.49	1.64	1.23
Agricultural College	7	.85	.30	1.22	.59
	8	2.12	.41	1.28	.89
	9	1.97	.31	1.46	.43
Van Buren County	10	.83	.13	.51	.46
Lake County	11	.90	.23	.62	.28
Mason County	12	.65	.22	.66	.12
	13	2.10	.30	1.00	.89
Osceola County	14	1.19	.29	.80	.64
Mecosta County	15	1.96	.44	.94	.48
	16	1.80	.33	1.14	.49
Wexford County	17	.83	.15	.65	.24
Missaukee County	18	1.95	.28	1.15	.96
Grand Traverse County	19	.89	.13	1.37	.41
Benzie County	20	1.10	.21	.55	.27
Antrim County	21	.98	.18	.95	.36

[a] Bul. 22, La. Agr. Expt. Sta., 1893, p. 739.

[b] Ann. Rpt. Me. Agr. Expt. Sta., 1894, p. 15.

[c] Ann. Rpt. Md. Agr. Expt. Sta., 1889, p. 86.

[d] Bul. 99, Mich. Agr. Expt. Sta., 1893, pp. 6-15.

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO.	Magnesia (MgO).
Michigan—Continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Grayling	22	0.20	0.05	0.20	0.12
	23	.33	.04	.24	.17
	24	.30	.01	.32	.15
Kalamazoo	26	.34	.88	6.09	.81
Grand Haven	27	.20	.69	5.02	.62
Luce County	28	.42	.46	4.18	.75
Isabella County	29	.86	.19	.87	.27
Midland County	30	1.85	.49	1.64	1.23
Clare County	31	.54	.15	.36	.16
	32	1.90	.36	.99	.73
Lake County	33	.73	.14	.35	.30
Gratiot County	34	.92	.14	.68	.30
Bay County	35	1.18	.38	1.18	.46
Montcalm County	36	1.13	.20	.82	.31
Otsego County	37	.61	.14	.40	.13
Iosco County	38	1.10	.16	.93	.36
Minnesota:[a]					
Red Wing	285	.15	.10	.47	.21
Gilford	265	.33	.10	.56	.38
Good Thunder	269	.46	.09	.60	.16
Langdon	290	.17	.15	.48	.20
Eden Prairie	304	.11	.22	.74	.41
Faribault County	300	.30	.19	.70	.40
Grant County	266	.21	.10	1.00	.42
McLeod County	234	.25	.20	.23	.36
Martin County	261	.31	.15	.58	.19
Meeker County	302	.25	.18	2.48	.97
Goodhue County	257	.16	.30	.76	.81
Warren	203	.54	.38	2.44	1.85
	298	.50	.31	2.40	1.91
Crookston	202	.60	.29	2.55	.67
	236	.54	.24	2.49	.62
	272	.90	.13	1.07	.84
Twin Valley	306	.18	.13	.48	.25
Gossen	308	.30	.19	1.20	.80
Moorhead	275	.73	.20	1.29	.39
	224	.45	.35	.69	.38
	312	.28	.30	.65	.77
	222	.18	.21	.61	.65
	259	.34	.21	1.00	.25
	249	.32	.26	1.53	.65
	298	.32	.25	.92	.24
Worthington	326	.36	.65	1.06	.82
Benson	214	.46	.27	13.56	2.57
Fergus Falls	208	.17	.32	.54	.33
Alexandria	210	.44	.31	1.26	.35
Wadena	245	.28	.20	.60	.60
Park Rapids	230	.26	.15	.61	.18
Henning	292	.19	.36	.63	.13
Fair Haven	273	.20	.21	.77	.25
Mille Lacs	216	.14	.22	.38	.29
Pine	236	.08	.04	.11	.12
Hinckley	228	.18	.12	.76	.25
New Duluth	232	.27	.33	.32	.51
Wyanette	288	.08	.10	.21	.13
Saint Cloud	212	.85	.19	.26	.10
Duluth	264	.25	.45	.51	.12
Farmington	277	.20	.20	.46	.18
	279	.19	.20	.48	.27
Rolling Stone	239	.30	.23	.41	.39
Faribault	280	.23	.21	.54	.30
Owatonna	283	.23	.13	.48	.18
Experiment station	242	.30	.23	.51	.26
Austin	218	.32	.38	.48	.45
Wells	220	.36	.25	1.10	.99
Mankato	294	.19	.30	.53	.11
Polk County	464	.84	.29	1.10	.59
Norman County	320	.43	.30	5.05	2.57
Polk County	317	.34	.27	.71	.63
Wilkin County	448	.37	.20	.89	.53
	446	.27	.22	1.36	.30
Lincoln County	428	.29	.15	.88	.73
Chippewa County	442	.38	.26	.56	.74
	444	.46	.26	1.05	.70
Kandiyohi County	414	.25	.21	.70	.43
Grant County	266	.21	.10	1.00	.42
Martin County	261	.31	.25	.58	.19

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[a] This and the following samples to and including No. 257 from Ann. Rept. Minn. Agr. Expt. Sta., 1893; Nos. 203 to 329, Bulls. 30, 41, and 65, Minn. Agr. Expt. Sta.

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
Minnesota—Continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Meeker County	202	0.25	0.18	2.48	0.97
Wright County	432	.13	.23	.69	.42
McLeod County	462	.17	.20	.95	.66
Hennepin County	430	.30	.38	.51	.50
	451	.29	.32	.92	.45
Ramsey County	374	.28	.19	.52	.21
Wadena County	420	.30	.45	.94	.51
Becker County	422	.25	.47	.88	.55
Todd County	418	.17	.31	.56	.26
	424	.16	.13	.47	.24
Ottertail County	456	.15	.16	.78	.17
Cass County	414	.27	.20	.28	.11
Dakota County	436	.32	.20	.31	.38
	434	.30	.28	.53	.40
Wabasha County	468	.27	.26	.67	.54
Goodhue County	285	.22	.10	.40	.17
	257	.26	.30	.76	.81
Rice County	489	.32	.16	.51	....
Houston County	483	.34	.22	.42	.47
Freeborn County	470	.27	.26	.60	.46
Fillmore County	487	.41	.12	.45	.66
Faribault County	300	.30	.19	.70	.40
Olmsted County	485	.61	.24	.30	.77
Blue Earth County	269	.46	.19	.60	.16
Washington County	440	.26	.19	.29	.43
	314	.17	.20	.28	.11
Chisago County	499	.20	.20	....	....
Pine County	426	.18	.13	.33	.29
	228	.25	.12	.76	.25
Carlton County	474	.12	2.61	.20	.39
Chisago County	497	.34	.10	.22	....
	495	.31	.11	.17	....
Pine County	501	.38	.22	.47	....
Dakota County	563	.42	.19	.41	.40
	557	.29	.16	.33	.34
	535	.44	.16	.46	.25
	513	.23	.36	.58	.69
Goodhue County	553	.40	.17	.64	.70
	521	.48	.16	.69	.61
	527	.51	.20	.70	.76
	616	.50	.20	.56	.23
	555	.44	.14	.49	.64
	577	.38	.16	.50	.51
	573	.37	.13	.59	.61
	572	.55	.17	.48	.51
Hennepin County	542	.43	.23	.42	.41
Wabasha County	515	.20	.31	.64	.72
	618	.44	.22	.41	.10
	503	.20	.38	.49	.44
Winona County	596	.38	.15	.43	.51
	597	.45	.26	.52	.45
	598	.44	.18	1.69	1.17
Freeborn County	592	.54	.27	.61	.53
	594	.46	.25	.67	....
	567	.42	.18	.52	.29
	584	....	.29	2.36	.77
	586	.29	.22	1.94	6.12
	519	.63	.11	.40	.57
Mower County	533	.37	.19	.49	.33
Fillmore County	633	.49	.32	3.22	.20
Waseca County	505	.21	.48	.53	.44
	455	.57	.22	.70	.29
Martin County	561	.57	.11	.93	.76
Watonwan County	531	.49	.15	.81	.54
	606	.45	.19	.40	.17
	607	.36	.19	.77	.37
	608	.46	.24	2.55	.20
Nicollet County	523	.52	.20	.62	.73
Sibley County	559	.43	.16	.63	.45
Renville County	511	.42	.32	.97	.60
Lyon County	599	.56	.24	.57	.67
Lac qui Parle County	568a	.50	.19	14.00	1.33
	502	.54	.29	1.65	.67
Big Stone County	537	.35	.20	.68	.73
Kandiyohi County	624	.58	.20	1.42	.38
	588	.34	.14	.72	.60
	590	.50	.18	1.31	.74
	620	.62	.21	.87	.11
Swift County	609	.33	.24	.58	.33
	525	.39	.16	.99	.27

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
Minnesota—Continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Polk County	551	0.57	0.19	0.74	0.68
Ottertail County	517	.51	.16	.97	.61
	632	.44	.14	.71	.25
Becker County	571	.73	.16	.89	.76
Norman County	612	.66	.34	4.60	2.00
	613	.60	.32	8.67	1.69
	614	.73	.16	1.10	.60
Kittson County	569	1.16	.19	1.25	.58
Hubbard County	611	.20	.04	.48	.25
Isanti County	509	.10	.23	.38	.29
Sherburne County	579	.18	.11	.28	.21
Morrison County	575	.23	.14	.44	.34
Itasca County	540	.15	.11	.42	.30
	544	.55	.07	.74	1.04
	548	.18	.13	.19	.22
Beltrami County	666	.35	.14	.76	.36
Stearns County	600	.27	.10	.51	.24
	602	.37	.09	.27	.13
	630	.43	.21	.70	.37
Chisago County	529	.36	.30	1.22	.41
Mississippi:[a]					
Senatobia	1,489		.270	1.560	.460
McNeil Experiment Station		.142	.023	.220	.162
		.210	.017	.170	.140
North Dakota:[b]					
Red River Valley (average 21 samples)		.54	.19	4.16	.81
James River Valley (average 5 samples)		.48	.27	1.07	.57
Sheyenne River Valley (average 2 samples)		.54	.17	14.67	.93
Mouse River Valley (average 4 samples)		.34	.18	2.19	.51
Devils Lake region (average 10 samples)		.57	.12	6.08	.61
Turtle Mountains (average 8 samples)		.55	.14	.77	.47
Wells County (average 2 samples)		.45	.19	.41	.28
Rolette County (average 7 samples)		.45	.25	.96	.14
West Missouri (average 2 samples)		.35	.19	.32	.43
Station farm	422	.45	.27	1.25	Trace.
	423	.44	.33	.83	Trace.
	424	.60	.38	.80	Trace.
	425	.73	.40	.86	Trace.
	426	.54	.38	1.01	Trace.
	427	.63	.39	.85	Trace.
	428	.50	.39	1.05	Trace.
Mayville, Old		.22	.37	2.10	.08
Mayville, New		.18	.31	2.00	.07
Station Plats		.77	.21	1.47	.72
		.61	.20	.65	.23
	1	.79	.27	1.08	.34
	2	.82	.29	1.39	.50
	24	.78	.38	1.07	.44
	25	.96	.39	1.19	.68
Oregon:[c]					
Lincoln County	1A	1.76	.06	.23	1.13
	1B	.10	.27	1.40	1.65
Washington County	1C	.03	.03	.34	1.71
	1D	.16	.32	.63	1.18
Wasco County	1E	.00	.02	.65	1.41
Washington County	1F	.12	.09	.75	.13
	1G	.28	.34	.13	.90
	1H	.26	.34	.76	.71
Benton County	1I	.11	.01	1.60	1.78
	1J	.47	.05	1.60	1.03
Polk County	1K	.24	.33	.60	.55
Washington County	1L	.11	.30	1.47	1.27
Lincoln County	1M	.12	.08	.53	.82
Washington County	1N	.19	.06	.43	1.54
Lincoln County	1O	.26	.21	.31	.52
	1P	.38	.33	.30	.40
	1Q	.33	.12	.27	.25
	1S	.16	.18	.42	.98
	1T	.22	.12	.45	2.04
	1U	.33	.11	.27	.52
Lane County	1V	.09	.16	.60	.27
Linn County	1W	.15	.11	3.51	.21

[a] Sample 1489, Ann. Rpt. Miss. Agr. Expt. Sta., 1890; samples from McNeil Expt. Sta., Bul. 99, Miss. Agr. Expt. Sta.

[b] This and the following samples from Bul. 35, N. Dak. Agr. Expt. Sta. (1899), and Ann. Rpt. N. Dak. Agr. Expt. Sta., 1901.

[c] Samples 1A to 627, Bul. 50, Oreg. Agr. Expt. Sta. (1898) samples 2382 to 2542, Ann. Rpt. Oreg. Agr. Expt. Sta., 1903.

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K$_2$O).	Phosphoric acid (P$_2$O$_5$).	Lime (CaO).	Magnesia (MgO).
Oregon—Continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Douglas County	1X	0.44	0.16	2.05	0.42
Crook County	1Y	.83	.08	1.21	1.11
Union County	1Z	.84	.07	.76	.24
Washington County	....	.18	.23	1.49	.26
Marion County	2A	.94	.13	.75	.97
	2B	.04	.28	.10	.91
Baker County	406	.51	.14	1.13	1.93
	407	.03	.02	.94	.01
Polk County	409	.02	.02	2.01	.02
	424	.39	.47	.75	.87
Washington County	425	.02	.04	.82	.85
Marion County	426	.47	.63	.40	.96
Clackamas County	447	.29	.31	.59	.80
Lincoln County	448	.11	.40	.46	.63
Washington County	449	.11	.25	.50	.00
	2N	.51	.54	.49	.71
	623	.17	.12	1.13	.38
	624	.23	.21	.04	1.45
Lane County	454	.19	.13	.65	.46
Polk County	625	.47	.22	.56	.79
Umatilla County	408	.23	.25	1.86	.09
Benton County	597	.33	.25	.89	.80
Jackson County	612	.33	.14	2.32	.83
	613	.21	.14	5.15	.72
Josephine County	615	.19	.21	2.49	.46
	615½	.27	.23	3.49	.43
Linn County	643	.39	.40	.55	.71
Wasco County	644	.12	.28	1.41	1.10
Marion County	626	.12	.29	.95	.62
	622	.46	.07	Trace.	.05
Multnomah County	629	.25	.40	1.27	1.23
Josephine County	616	1.85	.06	3.11	3.36
Douglas County	618	1.27	.28	.13	.00
Wasco County	762	.31	.22	.82	.15
	763	.20	.25	.38	.24
	764	.41	.82	.84	.24
Coos County	765	.20	.11	.52	.16
	766	.29	.38	.41	.60
Benton County	410	.06	.03	.66	.00
	411	.21	.34	.46	.05
Marion County	628	.48	.19	.32	.50
	628½	.52	.22	.34	.33
Yamhill County	768	.26	.23	.63	.63
	769	.38	.76	.43	.53
Marion County	619	.50	.35	.35	.22
	619½	.62	.30	.00	.28
Josephine County	617	.31	.05	.28	.35
	622	.30	.00	.72	.33
Marion County	627	.38	Trace.	.71	.91
	2382	....	.08	....	....
	2383	....	.15	....	....
	2407	.12	.23	.36	....
	2410	.15	.17	.24	....
	2425	.06	.11	14.36	....
	2448	.19	.21	.40	....
	2449	.18	.24	.33	....
	2450	.22	.20	.41	....
	2540	.26	.25	1.50	.64
	2541	.26	.39	5.63	2.19
	2542	.37	.36	1.25	.86
Washington[a]	11	.331	.182	1.512	1.527
	16	.530	.139	1.180	.733
	17	.432	.100	1.212	.788
	19	.202	.038	.655	Trace.
	20	.007	.054	.769	.426
	21	.136	.313	.379	.036
	22	.112	.079	1.112	.031
	25	.590	.353	.362	.281
	26	.233	.198	.397	.031
	27	.015	.140	.109	.022
	28	.277	.300	.082	.065
	29	.448	.345	.781	.122
	31	.650	.543	.431	.033
	32	.012	.311	.130	.033
	33	.047	.399	.398	.018
	34	.120	.172	.675	.116

[a] Buls. 13, 23, and 55, Washington Agr. Exp. Sta., 1894, 1902.

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Washington	39	0.274	0.166	0.979	0.015
	40	.058	.159	1.758	.647
	41	.442	.191	.930	.362
Spokane County	30	.436	.265	.604	.043
	114	.374	.096	.644	.297
	119	.663	.070	.874	.072
	120	.651	.096	.908	.270
Jefferson County	42	.019	.109	.154	.335
	43	.022	.085	.579	.036
	175	.054	.089	.219	.212
San Juan County	44	.000	.106	1.468	.159
	45	.000	.365	.538	.432
	46	.000	.274	.448	.223
Okanogan County	71	.341	.112	2.084	.018
	74	.347	.288	4.679	.081
	76	.006	.096	.714	.011
	77	.019	.112	.614	.027
Whitman County	5	.635	.142	1.081	.727
	72	.471	.361	.457	.256
	73	.332	.122	.514	.283
Whatcom County	75	.006	.294	.324	.546
	78	.142	.285	.409	.000
	79	.021	.067	.359	.151
	139	.316	.139	1.234	.454
	140	.483	.054	1.044	.112
	141	.275	.144	1.322	.000
	142	.319	.266	.892	.014
Skagit County	82	.111	.090	1.049	.009
	83	.057	.070	.832	.005
	84	.006	.045	.892	.005
	85	.015	.144	.892	.007
	86	.129	.267	1.082	.006
	100	.186	.304	.474	Trace.
	101	.028	.205	.518	.018
Yakima County	91	.189	.128	2.389	.092
	92	.149	.174	.909	.068
	93	.310	.141	1.259	.364
	94	.047	.154	1.469	.421
	137	.455	.029	1.154	.013
King County	102	.004	.057	.389	....
	129	.057	.070	.599	.216
	179	.142	.390	.404	.189
Thurston County	176	.076	.320	.506	.235
Snohomish County	103	.051	.176	.414	.018
	177	.218	.237	.704	.332
Island County	105	.145	.067	.564	.357
	122	.626	.344	1.214	.209
Clarke County	162	.335	.137	.333	.054
Clallam County	111	.154	.240	.525	.023
	128	.171	.115	.834	.450
Spokane County	115	.550	.154	.432	.306
	198	.534	.216	.630	.036
	199	.385	.190	.600	.054
Okanogan County	218	.147	.245	27.940	.605
Walla Walla County	289	.378	.320	1.200	.400
	290	.465	.287	1.450	.399
	291	.485	.351	1.350	.345
	292	.440	.320	1.550	1.003
Franklin County	293	.437	.351	1.050	.299
	294	.393	.325	1.300	.362
Kitsap County	80	.085	.048	1.971	.018
	81	Trace.	.019	.308	.281
	124	.111	Trace.	.659	.032
	126	.054	.045	.534	.036
	106	.003	.029	1.296	.476
Experiment Station Farm	373	.107	.177	.150	.010
	374	.129	.136	.175	.148
	375	.117	.192	.005	.109
	376	.092	.135	.010	.091
	377	.020	.336	.220	.091
Thurston County	184	.188	.312	.638	.048
	102	.004	.058	.389	.561
	231	.189	.297	.450	.112
Pierce County	37	.003	.205	.569	.048
	219	.181	.192	.940	....
	220	.144	.409	.760	....
Snohomish County	212	.146	.217	1.140	.091
	221	.150	.307	.520	....
King County	200	.087	.159	.410	.016

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Utah:[a]					
College Farm	90	0.046	0.115	3.45	2.29
	93	.051	.103	3.08	2.52
Cache Valley, south end	2067	1.04	.18	.83	.50
	2074	.62	.18	.69	.55
	2162	1.15	....	.60	.49
	2070	.74	.24	.86	.67
	2079	1.48	.39	1.66	2.42
	2062	.69	.24	2.10	.56
Cache Valley, west side, south half	2058	.77	.19	.84	.61
	2085	.76	.24	.85	.64
	2071	1.34	.21	1.00	.98
	2073	1.50	.27	1.01	.72
	2163	1.43	.27	1.25	.86
	2160	1.34	.25	1.28	1.16
	2166	1.09	.42	1.55	.51
Cache Valley, west side, north half	2061	.47	.14	.46	.21
	2078	.67	.18	.99	.67
	2063	.68	.16	.67	.33
	2064	.71	.20	.69	.49
	2081	1.37	.29	1.31	.50
	2065	1.51	.25	1.06	.89
Cache Valley, north end	2169	1.18	.15	1.85	.88
	2167	1.56	.30	3.14	.67
	2057	.50	.30	.67	.13
Cache Valley, east side	2055	1.16	.20	1.68	.54
	2059	1.39	.18	2.22	1.47
Middle Cache Valley	2172	1.05	.21	7.35	1.37
	2046	.53	.20	1.50	.21
	2047	.50	.25	2.43	.58
	2048	.60	.18	.59	.73
	2049	.30	.18	.54	.33
	2050	.44	.20	.56	.41
	2051	.90	.25	1.52	.16
	2052	.31	.18	.62	.31
	2053	.36	.15	.47	.26
	2084	2.69	.23	6.39	.66
	2083	1.20	.26	8.36	1.56
Sanpete Valley	1819	.27	.16	8.37	.13
	1818	.68	.21	9.81	.73
	1817	.72	.11	10.65	.07
	1816	.80	.22	13.09	.84
	1821	.51	.17	22.54	1.29
	1824	.65	.15	17.35	.29
	1826	.95	.20	14.89	.42
	1827	1.24	.24	13.16	.36
	1808	.58	.17	9.91	1.40
	1807	.67	.18	9.53	1.66
	1809	1.03	.19	14.01	1.20
	1805	.58	.14	12.84	.71
	1806	.95	.16	22.05	.55
	1825	.81	.17	13.17	1.90
	1811	.75	.23	13.99	.46
	1812	.60	.20	13.24	.59
	1813	1.25	.16	13.76	.75
	1814	.95	.12	13.17	.29
Wyoming:[b]					
Laramie Experiment Farm	5	.56	.15	1.47	.14
	7	.64	.14	.82	.76
Lander Experiment Farm	37	.68	.15	.64	1.36
	51	.61	.20	6.63	1.65
Saratoga Experiment Farm	19	.64	.12	3.41	.95
	43	.73	.13	.74	1.15
Sheridan Experiment Farm	33	.52	.28	.69	.94
Sundance Experiment Farm	27	.68	.18	4.97	3.21
Wheatland Experiment Farm	21	.63	.14	.87	.85
Tennessee[c]	1	.120	.040	.053	.140
	2	.180	.074	.060	.213
	3	.330	.104	.180	.342
	4	.312	.057	.163	.455
	5	.092	.021	.050	.065
	7	.403	.017	.073	.291
	6	.340	.022	.100	.355
	8	.218	.010	.100	.090
	9	.410	.158	.510	.290

[a] Ann. Rep. Utah Agr. Expt. Sta. (1891); Bul., 52, Utah Agr. Expt. Sta., 1898.
[b] Bul. 6, Wyo. Agr. Expt. Sta. (1892).
[c] Bul. 3, Tenn. Agr. Expt. Sta. (1897).

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Tennessee	10	0.393	0.078	0.278	0.355
	11	.285	.020	.093	.157
	12	.378	.026	.132	.184
	13	.409	.069	.212	.270
	14	.380	.071	.205	.246
	15	.416	.113	.199	.290
Greene County	....	.092	.021	.050	.085
Knox County	....	.180	.074	.060	.213
		.120	.040	.053	.140
Grundy County	....	.403	.017	.073	.291
Franklin County	....	.340	.022	.100	.265
Monroe County	....	.312	.057	.163	.455
Loudon County	....	.380	.104	.180	.342
Dyer County	....	.416	.113	.199	.290
Gibson County	....	.409	.069	.212	.270
Coffee County	....	.218	.010	.100	.090
Benton County	....	.285	.020	.093	.157
Carroll County	....	.378	.026	.132	.184
Fayette County	....	.380	.071	.205	.246
Maury County	....	.410	.158	.510	.290
Robertson County	....	.393	.078	.278	.355
New Hampshire[a]	1	.64	.36	.63	.62
	3_1	1.06	.16	.63	....
	3_2	1.06	.09	.76	.53
	5_1	.91	.08	.73	.74
	5_2	.97	.05	.77	.68
New York[b]	E	.95	.115	.60	1.02
	D	.89	.093	.62	.85
	D^3	.98	.134	.68	1.94
	F^1	1.04	.117	.70	1.04
Missouri[c]	1a	1.32	.08	.63	.44
	1b	1.23	.09	.55	.38
	2a	2.54	.07	.63	.40
	2b	2.57	.07	.59	.45
	3a	1.17	.06	.47	.29
	3b	1.13	.06	.42	.21
	4	1.38	.06	.62	.34
Nevada[d]	11	.488	.210	9.056	3.776
	12	.364	.125	7.492	3.031
	13	.616	.030	1.990	1.339
	14	.470	.104	11.549	2.810
	15	.628	.178	17.831	8.404
	1	.313	.479	1.86	1.03
	2	.306	.291	7.716	1.570
	3	.016	.040	9.580	2.332
	4	.302	.157	2.447	1.403
	5	.457	.223	7.223	1.283
	6	.227	.163	1.503	.690
	7	.128	.019	2.801	.574
	8	3.34	.215	1.407	1.314
	9	.277	2.292	1.900	1.521
	10	.682	.190	2.001	1.470
	1501	.81	.35	2.50	1.18
	1503	1.12	.35	2.90	.23
	1504	1.03	.32	5.00	.17
	[e] 1523	1.79	.30	4.15	.23
	1533	.68	.41	.80	4.14
	1534	1.05	.26	5.15	.22
	1508	.51	.45	4.35	1.29
	1509	.97	.73	2.70	.21
	1510	.73	.27	3.30	1.09
	1511	.42	.19	2.45	1.08
	1512	.91	.28	2.20	.26
	1513	.42	.38	1.85	Trace.
	1514	.92	.79	2.30	.18
	1515	.54	.38	3.90	1.55
	1518	.43	.19	12.00	2.34
	1519	.32	.35	7.99	1.67
	1520	.42	.32	2.40	1.10
	1521	Trace.	.30	1.55	.96
	1523	Trace.	.26	14.65	1.81
	1533	.72	.26	12.50	5.10
	1534	.45	.35	8.10	2.02

[a] Ann. Rept. N. H. Agr. Expt. Sta., 1893.
[b] Ann. Rept. N. Y. Agr. Expt. Sta., 1889.
[c] Bul. 5. Mo. Agr. Expt. Sta. (1889).
[d] Bul. 19, Nevada Agr. Expt. Sta. (1892, 1897); Ann. Rept. Nevada Agr. Expt. Sta., 1890.
[e] Nos. 1523, 1533, 1534 in this place are evidently original Nos. 1505, 1506, 1507 misnumbered.

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Nevada	1545	0.46	0.55	1.60	1.06
	1546	.32	.26	1.20	.45
	1547	....	.38	1.85	.45
	1548	.32	.26	1.20	.45
	1549	.40	.38	1.48	.34
West Virginia [a]	12	.243	.153	.104	....
	13	.593	.121	.335	....
	14	.808	.167	.451	....
	15	.403	.105	.181	....
	16	.705	.103	.062	....
	17	.481	.088	.055	....
	46	.250	.115	.081	....
	47	.516	.185	.404	....
	48	.469	.184	.116	....
	49	.781	.095	.059	....
	50	.888	.121	.076	....
	51	.401	.093	.111	....
	53	.479	.211	.081	....
Ohio:[b]					
East farm, Wooster	840	.25	.07	.35	.30
	844	.24	.081	.30	.43
	830	.20	.08	.27	.48
	834	.28	.08	.29	.25
	800	.15	.064	.21	.43
	804	.15	.091	.25	.43
	810	.16	.101	.37	.42
	814	.14	.089	.23	.42
	820	.16	.11	.25	.40
	824	.19	.129	.33	.40
	850	.29	.07	.32	.23
	852	.27	.079	.20	.35
	854	.25	.08	.24	.44
	856	.24	.097	.28	.37
	858	.20	.118	.25	.43
	860	.28	.08	.30	.36
South farm, Wooster	872	.28	.151	.225	.368
	876	.27	.118	.187	.373
	862	.39	.167	.24	.45
	866	.29	.191	.20	.39
	868	.34	.156	.202	.358
University farm, Columbus	1	.64	.12	.64	.76
	4	.53	.20	.60	.52
	7	.62	.17	.59	.71
	10	.55	.17	.46	.64
	13	.59	.15	.45	.61
	16	.53	.10	.63	.58
	19	.62	.11	.68	.62
	22	.43	.12	.45	.49
Test farm, Strongville	1852	.18	.097	.20	.44
	1864	.25	.064	.16	.31
	1368	.22	.121	.10	.54
Test farm, Strongville	1874	.21	.099	.19	.34
	1880	.20	.08	.23	.40
	1884	.25	.12	.28	.40
	1810	.23	.197	.19	.42
	1820	.19	.161	.18	.56
	1826	.19	.113	.27	.461
	1832	.28	.227	.30	.57
	1838	.20	.126	.354	.44
	1844	.11	.126	.23	.54
	1846	.15	.121	.22	.50
Northwest test farm, Neapolis	1802	.05	.11	.11	.09
	1806	.05	.16	.49	.18
	1803	.06	.10	.08	.14
	1807	.06	.12	.41	.15
	1786	.046	.120	.07	.10
	1792	.060	.130	.31	.14
	1787	.040	.110	.07	.11
	1793	.090	.120	.22	.15
Germantown	4253	.142	.102	.11	.31
Carpenter test farm	4255	.193	.124	.18	.33
	4257	.181	.101	.18	.26
Wooster experiment farm, first 12 inches	....	.25	.80	.313	.356
Strongville, first 12 inches	....	.251	.145	.205	.474
Columbus, O. S. U., first 12 inches	....	.563	.143	.621	.623
Neapolis, first 12 inches	....	.043	.115	.070	.105

[a] Buls. 28 and 99, W. Va. Agr. Expt. Sta. (1892, 1906).
[b] Buls. 110 and 150, Ohio Agr. Expt. Sta.

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
Oklahoma:[a]		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Virgin soil, Station farm	7	0 44	0.06	0.95	0.21
Virgin soil	10	.80	.04	.44	.16
Virgin soil	5	.32	.06	.76	.18
Pennsylvania:[b]					
Donegal	....	.62	.191	.61	1.26
Rocky Springs	....	.67	.265	.41	2.05
Connecticut, New Milford	....	.23	.22	.32	.78
North Carolina, Granville County	....	.02	.02	.07	.02
South Carolina,[c] Spartanburg farm	13	.142	.057	.027	.081
	17	.090	.066	.037	.043
	15	.100	.011	.045	.110
Columbia farm	1	.171	.044	.019	.040
	3	.050	.107	.022	.072
	5	.089	.022	.046	.124
Darlington farm	19	.052	.034	.025	.043
	21	.050	.037	.062	.047
	23	.040	.051	.028	.003
Big River	....	.541	.155	.188	.811
Rhode Island:[d]					
Kingston plain	165	.155	.127	.569	.209
Kingston upland	166	.175	.106	.448	.264
Warwick	167	.124	.029	.410	.290
Lime Rock	168	.184	.092	1.295	1.141
Block Island	169	.136	.067	.273	.209
Middletown	170	.164	.099	.252	.368
East Providence	171	.126	.120	.495	.356
Tennessee:[e]					
Hamblen County	58	.12	.04	.08	.13
	55	.10	.04	.10	.12
Knox County	606	.09	.04	.12	.22
	31	.14	.03	.09	.11
	48	.16	.05	.14	.20
Hamblen County	64	.23	.04	.16	.17
Knox County	25	.28	.09	.17	.15
McMinn County	172	.38	.06	.12	.37
Hamblen County	60	.28	.10	.04	.13
	66	.08	.01	.09	.11
Knox County	32	.29	.09	.11	.10
	602	.26	.08	.12	.22
	608	.09	.03	.08	.15
Hamblen County	51	.85	.10	.82	.42
	57	.36	.07	.17	.25
Knox County	29	.43	.07	.22	.24
	821	.26	.09	.10	.30
McMinn County	174	.68	.07	.31	.53
Roane County	595	.18	.07	.06	.12
Washington County	597	.18	.07	.10	.18
Anderson County	129	.21	.17	.12	.19
Hamblen County	49	.24	.08	.12	.24
Knox County	600	.36	.16	.30	.29
	603	.41	.18	.38	.73
	30	.34	.09	.20	.35
	37	.18	.16	.18	.31
	553	.18	.11	.16	.22
Roane County	593	.30	.09	.26	.33
Blount County	35	.52	.18	.17	.56
Hamblen County	53	.91	.09	.73	.96
Knox County	26	.45	.12	.43	.48
	612	.41	.09	.41	.52
Cumberland County	605	.06	.03	.10	.10
	746	.18	.06	.06	.27
	67	.08	.02	.04	.14
Cumberland County	68	.06	.03	.04	.16
Coffee County	750	.23	.07	.23	.21
Franklin County	39	.31	.09	.21	.30
	565	.27	.10	.16	.23
	566	.34	.04	.14	.27
Humphreys County	592	.23	.05	.13	.26
Lawrence County	569	.16	.08	.08	.21
	570	.28	.06	.08	.31
Montgomery County	742	.22	.05	.14	.23
Stewart County	581	.15	.05	.12	.18
	583	.17	.51	.15	.18

[a] Bul. No. 5, Okla. Agr. Expt. Sta. (1894).
[b] Ann. Rept. Pa. Agr. Expt. Sta., 1894.
[c] Ann. Rept. S. C. Agr. Expt. Sta., 1889.
[d] Bul. 28, R. I. Agr. Expt. Sta. (1894).
[e] Bul. 78, Tenn. Agr. Expt. Sta. (1906).

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
Tennessee—Continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
White County	571	0.20	0.06	0.14	0.16
	574	.22	.07	.13	.49
	563	.21	.07	.09	.25
	564	.32	.05	.14	.34
Coffee County	867	.09	.04	.14	.15
Dickson County	591	.16	.03	.08	.24
	589	.10	.03	.10	.15
	590	.31	.02	.02	.49
Houston County	585	.15	.03	.10	.19
	586	.12	.03	.04	.24
	583	.15	.05	.09	.18
	579	.13	.09	.34	.16
Lewis County	587	.18	.02	.06	.17
	588	.25	.04	.03	.35
Putnam County	843	.07	.03	.06	.11
Warren County	806	.14	.04	.09	.14
	575	.08	.01	.07	.13
	580	.11	.01	.07	.13
Bedford County	751	.28	.14	.09	.37
	615	.17	.08	.28	.19
	616	.15	.08	.25	.21
	572	.33	.12	.24	.33
	573	.49	.05	.31	.42
	577	.46	.19	.57	.44
	578	.19	.05	.05	.19
	747	.26	.16	.14	.24
	748	.30	.11	.10	.27
	170	.32	.26	.20	.32
	171	.42	.17	.18	.40
	175	.43	.14	.56	.36
	176	.43	.15	.61	.34
Davidson County	617	.70	.06	.45	.79
Lincoln County	42	.44	.31	.31	.53
Marshall County	561	.19	.32	.20	.30
	633	.25	.26	.17	.28
	660	.33	.27	.27	.35
Rutherford County	635	.29	.08	.22	.23
Smith County	822	.22	.21	.17	.21
Sumner County	634	.24	.20	.23	.36
	160	.33	.26	.38	.28
	161	.29	.25	.20	.38
Williamson County	567	.33	.32	.20	.32
	568	.59	.97	.18	.23
Carroll County	662	.21	.07	.16	.21
	661	.32	.05	.10	.41
Chester County	659	.20	.11	.19	.21
Dyer County	664	.24	.08	.16	.25
Gibson County	158	.21	.06	.16	.25
	159	.26	.06	.11	.37
	668	.23	.08	.23	.23
Hardeman County	670	.35	.09	.22	.33
Henderson County	658	.23	.07	.16	.21
Henry County	663	.28	.07	.15	.21
Madison County	749	.31	.09	.09	.43
McNairy County	671	.20	.06	.11	.19
Obion County	669	.28	.09	.39	.42
Weakley County	666	.23	.07	.20	.24
	665	.34	.06	.11	.40
	667	.28	.08	.16	.26
Blount County	135	.76	.24	.24	.52
Giles County	576	.34	1.52	1.38	.34
	584	.42	1.70	2.25	.35
Roane County	594	.09	.04	.09	.23
White County	883	.22	.07	.13	.25
Montgomery County	871	.20	.05	.15	.23
	874	.38	.16	.25	.38
Maury County	885	.31	.21	.29	.35
Sumner County	873	.40	.38	.43	.39
Oregon:[a]					
Salem	2697	.15	.41	.37	.76
	2698	.20	.53	.48	.41
	2699	.26	.21	.80	.30
	2700	.12	.21	.54	.27
	2701	.44	.34	.32	.13
	2702	.39	.18	.45	.13

[a] Ann. Rep. Oregon Agr. Expt. Sta., 1905; Bradley Jour. Am. Chem. Soc., 28, 64 (1906).

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Oregon—Continued.					
Hubbard	2097	0.08	0.24	0.28	....
	2095	.14	.38	.31	....
	2096	.30	.40	.45	....
	2513	.19	.24	.71	0.56
	2525	.21	.19	.68	.87
	2539	.20	.26	.78	.85
	2554	.28	.14	1.11	.56
	2591	.10	.45	.94	.48
	2592	.18	.23	.29	.11
	2616	.51	.20	1.26	.90
	2617	.30	.22	.84	1.27
	2618	.13	.20	1.22	.79
	2619	.25	.21	1.98	1.31
	2621	.17	.19	1.09	.71
	2627	.19	.12	1.18	.29
	2623	1.16	.23	1.92	1.00
	2635	.10	.38	.54	.33
	2637	.17	.31	.48	.46
	2638	.16	.39	.67	.59
	2644	.26	.20	.76	.73
	2649	.12	.41	.67	.28
	2650	.16	.34	.94	.29
	2656	.09	.16	.55	.60
	2658	.10	.38	2.89	.60
	2689	.18	.36	.59	.18
	2690	.28	.26	1.44	.55
	2691	.43	.30	.91	.80
	2710	.43	.43	.53	.00
	2751	.43	.18	.45	.00
	2754	.37	.31	1.40	.95
	2758	.38	.38	.24	.79
	2781	.34	.09	.31	.91
	2838	.39	.22	.67	.80
	2841	.13	.14	.85	.48
	2843	.38	.25	.77	.44
	2844	.27	.34	.91	.35
	2847	.44	.25	.74	.58
	2848	.14	.24	.43	.35
	2854	.26	.16	.88	.46
	2855	.52	.39	.69	.67
	2869	.31	.25	.68	.76
	2921	.97	.24	1.35	1.24
Beaverdam soils	1	.14	.26	1.09	.22
	2	.28	.31	.26	.06
	3	.13	.22	.47	.10
	4	.10	2.30	.92	.33
	5	.20	.21	1.18	.25
North Carolina:[a]					
Oxford	....	.161	.06	.240	.047
Washington:[b]					
Spokane County	564	.829	.249	7.768	3.891
	641	.438	.108	.320	.142
	642	.304	.157	.334	Trace.
	643	.356	.300	.524	.398
	1030	.389	.185	.618	.295
Stevens County	77	.492	.122	.741	.150
	78	.225	.048	.741	.239
	161	.074	.083	.400	.234
	342	.162	.280	.350	.175
	435	.193	.400	.506	.374
	436	.229	.343	.494	.602
	655	.412	.217	.640	1.218
	656	.320	.089	.590	.469
	673	.336	.192	.499	.515
	1103	.099	.082	36.009	.684
Ferry County	446	.264	.124	.581	.548
	1872	.323	.257	.961	.262
	1873	.384	.241	.769	.216
Okanogan County	789	.294	.145	.668	.162
	790	.335	.170	.944	.319
Chelan County	158	.118	.078	.379	.301
	576	1.144	.122	1.365	.897
	1885	.518	.225	.714	.186
	1886	.649	.240	.852	.522

[a] Bul. 90 A. N. C. Agr. Expt. Sta. (1893).

[b] Bul. 85, Wash. Agr. Expt. Sta. (1908), Bul. 10, Div. of Chemistry, U. S. Dept. Agr. (1886).

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
Washington—Continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Lincoln County	741	0.436	0.117	0.842	0.584
	742	.524	.150	.755	.746
	1890	.517	.172	.563	.070
Douglas County	868	.335	.155	5.561	.976
	1024	.312	.050	1.120	.445
	1241	.298	.125	.568	.568
	1242	.442	.147	.762	.643
	1416	.380	.102	.563	.171
Adams County	1699	.450	.042	.618	.684
	1837	.411	.120	.591	.258
Whitman County	1888	.506	.187	.508	.194
Garfield County	1134	.567	.127	.726	.847
Asotin County	1133	.320	.080	.609	.632
	1420	.434	.052	.480	.239
	1431	.426	.042	.535	.095
	1432	.391	.047	.549	.210
Walla Walla County	1698	.358	.050	.824	.306
	1842	.413	.142	1.098	.140
	1845	.328	.037	.659	.104
	1846	.426	....	.770	.140
Columbia County	1135	.467	.110	.755	.793
	1411	.431	.162	.803	.437
	1412	.387	.152	.831	.509
Benton County	142	.427	.165	3.451	1.458
	708	.329	.105	1.570	1.009
	743	.312	.140	.944	.650
	745	.288	Trace.	.987	.712
	767	.304	Trace.	1.721	.940
	782	.415	Trace.	1.250	.562
Yakima County	194	.212	.136	1.631	.703
	545	.144	.130	1.770	1.270
	662	.293	.102	1.078	.500
	677	.125	Trace.	.648	Trace
Kittitas County	722	.471	.112	1.190	.793
	723	.462	.063	2.134	.850
	751	.794	.187	14.912	4.530
Klickitat County	8	.359	.150	.663	.365
	9	.413	.184	.390	.416
	190	.147	.069	.365	.354
	512	.028	.032	.790	Trace.
	1025	.116	.067	.550	....
Skamania County	661	.385	.138	.540	.297
	1102	.318	.118	.452	....
Clarke County	172	.166	.243	.486	.547
	330	.066	.198	.200	....
	331	9.178	.426	.862	.674
Wahkiakum County	602	.354	.212	.552	.228
	603	.610	.105	1.542	.962
	604	.134	.062	.145	....
Lewis County	783	.071	.062	.653	.405
	784	.162	.297	.769	.455
	785	.224	.107	.479	.086
	786	.124	.062	.421	.189
	1772	.184	.182	.164	.428
Chehalis County	143	.223	.118	.379	.256
	144	.144	.390	.393	.713
Mason County	869	.146	.155	1.625	.657
	1656	.440	.192	1.338	.703
	1657	.495	.192	1.433	.639
	1658	.475	.224	1.329	.465
	1659	.545	.224	2.099	1.411
	1660	.535	.216	1.418	.973
	1661	.940	.224	1.428	.947
	1662	.700	.224	1.449	.991
San Juan County	394	.151	.300	.873	.906
	870	.180	.125	1.060	.630
	871	.162	.087	1.031	.481
King County	159	.126	.044	.615	.907
	160	.157	.073	.693	.546
	499	.125	.286	1.089	.395
	500	.153	.190	1.089	.655
	744	.192	.124	1.321	.602
Dakota:[a]					
Prairie soils	6	.720	.112	.848	.668
	16	.725	.112	.852	1.535
	7	.745	.224	3.896	2.005

[a] Bul. 10, Div. of Chemistry, U. S. Dept. Agr. (1886) (locality unknown).

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Michigan:[a]					
Berrien County	2550	0.180	0.715	0.967	0.267
Indiana:[a]					
Boone County	2551	.510	.041	1.387	.771
New York:[a]					
Oswego County	A1	.320	.023	.350	.389
	A2	.425	.052	.440	.501
	A3	.305	.023	.350	.274
	A4	.595	.050	.564	.641
	B5	.400	.010	.753	.555
	B6	.475	.048	1.873	.868
	B7	.480	.038	.535	.642
	C8	.530	.176	.683	.793
	C9	.460	.176	.634	.746
Louisiana:[a]					
Rapides Parish	2574	1.470	.160	1.165	2.169
	2575	.930	.144	2.060	1.066
	2576	1.940	.193	.836	2.547
	2577	.805	.113	.414	1.131
	2579	.430	.097	.185	.346
	2580	.165	.00	.111	.090
	2581	.745	.080	.371	.839
	2582	.805	.096	.926	1.934
Nebraska:[b]					
Dawes County		.041	.822	1.892	.205
Cherry County		.410	.062	.498	.084
Brown County		.741	.062	.773	.060
Antelope County		.592	.039	.595	.031
Saunders County		.241	.112	.490	.334
Lancaster County		.197	1.421	.612	.420
Hamilton County		.054	.094	.468	.439
Mills farm		.806	.137	1.007	1.080
Division B		.593	.156	.715	.860
Wisconsin:[c]					
Experiment plat—					
Poor		.26	.18	1.44	
Medium		.27	.20	1.35	
Good		.30	.22	1.05	
Douglas County	127	1.27	.08	.75	2.08
Clark County	61	.08	.17	.63	.73
University farm	119	.37	.13	.53	.80
Shiocton	71	.17	.27	.83	.56
Lac du Flambeau	48	1.81	.18	1.05	.57
Peat	21	.46	.25	1.74	.44
Muck	22	1.43	.23	1.82	1.47
Texas:[d]					
Terrell		.17	.28	.55	.28
Forney		.316	.326	11.00	.543
Prairie soil		.837	.313	6.62	.81
Manor, Travis County		.576	.115	5.81	.317
Bell County, Waxie		.22	.12	23.98	.94
Bell County, Hammock		1.45	.18	1.03	.73
Waxahachie	I	.35	.15	5.17	.67
New Braunfels	II	.22	.41	7.32	1.31
Abilene		11.37	Trace.	4.04	1.40
Wichita		.426	Trace.	.74	Trace.
El Paso		.52	.34	.57	
Do		.43	.60	3.83	Trace.
Fort Bend		.46	.166	2.74	.24
Brazoria		1.091	.136	1.66	.126
Do		.885	.34	5.66	1.85
Do		.545	Trace.	.600	.73
Kaufman County		.68	.25	6.30	.46
Pecan Gap		.83	.128	.814	.32
Cherokee		.48	.243	.555	.126
Ridge soil		Trace.	.07	.16	Trace.
Pine Ridge		Trace.	Trace.	.00	.00
Tyler County		.06	.03	.44	.08
Do		Trace.	Trace.	.00	.08
Do		1.14	Trace.	4.04	1.41
Wichita County		.426	Trace.	.07	Trace.
College Clay		.80	.083	.60	.55

[a] Bul. 10. Div. of Chemistry, U. S. Dept. Agr. (1886).

[b] Buls. 38 and 60, Nebr. Agr. Expt. Sta., (1894, 1899).

[c] Ann. Rep. Wis. Agr. Expt. Sta., 1905.

[d] Buls. 25, 35, 43, 61, 82, and 99, Texas Agr. Expt. Sta.; Ann. Rep. Texas Agr. Expt. Sta. 1889.

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
Texas—Continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Alvin	1	0.093	0.024	0.958	0.464
	2	.46	.22	6.33	1.46
	3	.56	.15	8.17	2.01
Harris County		.17	.12	1.62	
Hitchcock	1		.04	.21	.695
	2		.035	.165	Trace.
	3		.037	.40	.08
	4		.019	.66	.122
Mesa		.397	.074	3.56	1.06
Beeville	1	.32	.04	.76	.47
	2	Trace.	.01	.67	.41
	3	Trace.	.06	.60	.13
Carson's farm	14	.02	.04	.17	.09
	16	.05	.05	.08	.05
	18	.01	.008	.04	.08
Huntsville	1	.05	.07	.09	.08
	2	.06	.06	.07	.18
	3	.05	.07	.18	.18
Willis	1	Trace.	.01	.18	.14
	4	.06	.01	.20	.27
	5	.37	.04	.16	.18
	7	.01	.03	.16	.28
	9	.04	.01	.04	.09
	11	.05	.29	.06	.18
Rice soils	95	.08	.016	.24	.18
	96	.29	.036	.55	.50
	97	.137	.019	.53	.70
	137	.143	.026	.24	.26
	141	.06	.023	.09	.16
	206	.396	.025	2.17	.83
Harris County		.29	.156	.65	.27
Victoria County		.43	.093	1.05	1.09
Brazoria County		.78	.148	1.88	1.91
Brownsville		1.31	.204	14.43	1.53
Houston County—					
Norfolk sand		.10	.01	.28	.31
Fine sand		.13	.01	.10	.03
Fine sandy loam		.18	.02	.09	.11
Orangeburg fine sand		.14	.05	.14	.06
Fine sandy loam		.71	.05	.10	.06
Lufkin fine sand		.11	.03	.15	.63
Clay		.14	.01	.43	.07
Susquehanna fine sandy loam		.11	.03	.05	.09
Clay		.20	.02	.29	.29
Anderson County—					
Norfolk sand		.07	.02	.05	.05
Fine sand		.10	.02	.06	.07
Fine sandy loam		.13	.01	.04	.05
Orangeburg fine sandy loam		.13	.03	.02	.04
Clay		.22	.06	.23	.22
Yazoo clay		.50	.14	3.14	.75
Lamar County—					
Orangeburg sandy loam		.25	.05	.12	.07
Fine sandy loam		.76	.02	.06	.07
Silt		.78	.12	1.52	.61
Clay		.40	.05	.08	.20
Houston black clay		.39	.05	1.05	.89
Clay		.19	.02	.35	.32
Sharkey clay		.83	.11	1.20	1.25
Lufkin clay		.13	.03	.07	.11
Sanders loam		.12	.04	.38	.25
Travis County—					
Houston black clay		.29	.07	5.66	.68
Yazoo sandy loam		.28	.07	10.60	1.06
Travis gravelly loam		.52	.04	1.47	.16
Lufkin fine sandy loam		.11	.02	.91	.10
Bexar County—					
Norfolk sand		.05	.02	.04	.02
Sandy loam		.17	.02	.05	.14
Houston black loam		.80	.06	3.06	.73
Clay		.32	.08	1.16	1.83
Orangeburg fine sand		.25	.02	.18	.01
Clay		.45	.09	.35	.35
Portsmouth sandy loam		.23	.03	3.40	.37
San Antonio clay loam		.47	.08	8.06	4.01
Austin fine sandy loam		.03	.11	23.64	.62

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
Texas—Continued.					
Hays County—		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Houston loam	....	0.29	0.01	0.37	0.23
Black clay	....	.20	.08	19.61	.62
Clay	....	.04	.09	19.32	.44
Crawford stony clay	....	.58	.18	12.40	.30
Silt clay	....	.78	.10	1.58	.83
Blanco loam	....	.05	.12	34.91	.91
Susquehanna fine sandy loam	....	.34	.04	.70	.20
Wabash clay	....	.41	.15	9.86	.96
Rio Grande Valley	1	....	.12	3.53	Trace.
	2	....	.29	3.68	.15
	3	....	.36	3.79	Trace.
Arkansas[a]	14727	.17	.07	.10	.14
	14728	.36	.10	.08	.29
	14729	.15	.07	.10	.20
	14730	.34	Trace.	.07	.22
	15353	.22	.16	.15	....
	15354	.30	.09	.08	....
California[a]	6356	1.07	.37	1.49	2.97
	6359	1.12	.53	1.47	3.39
	6831	.09	.05	.26	.21
	7936	.40	.16	4.46	1.75
	8051	1.81	.07	1.36	....
	8063	1.52	.05	1.06	....
	10147	.72	.14	.66	1.00
	3432	.33	.05	1.20	1.74
	6621	.92	.25	1.98	1.89
	6035	.11	.03	.67	.90
	6330	1.13	.30	1.29	2.22
	6352	1.84	.23	1.34	2.52
	124c	.55	....	2.82	1.18
	240c	.31	....	2.20	1.53
	241c	.54	....	1.96	1.73
	17958	.29	.06	....	....
	17962	.48	.06	1.79	....
	17968	.34	.03	....	....
	17974	1.20	.21	1.92	....
	17980	1.01	.09	1.61	....
Colorado[a]	7962	.52	.22	4.26	1.13
	7964	.61	.26	5.49	1.09
	723a	.71	.36	1.13	....
Miscellaneous	17177	.88	.06	5.14	.60
	17178	.57	.09	1.52	.19
	17180	.89	.13	2.54	.45
	17182	.82	.08	4.05	.20
	17184	.80	.11	2.03	.28
	17185	.79	.12	2.23	.21
	17186	1.27	.22	2.10	.23
	17190	.68	.22	.63	.48
	17193	1.02	.22	2.74	.62
	17195	.72	.11	.80	.13
	17196	.61	.15	.40	.62
	17197	.81	.22	.54	.19
	17198	.89	.35	3.60	.80
	17199	.54	.30	6.00	.36
	17201	.56	.24	.45	.40
District of Columbia[a]	6548	.53	.07	.57	.19
	726a	.29	.07	.26	.02
	727a	.49	.14	.46	.02
	728a	.36	.05	.26	.01
Florida[a]	2822	.04	.93	.24	.07
	3965	.03	....	.03	.16
	5284	.20	.02	.10	.07
	5286	.17	.08	.12	.05
	5288	.18	.02	.07	.06
	5290	.19	.03	.15	.07
	5391	.04	.05	.12	.01
	5392	.05	.04	.08	.02
	5403	.06	.04	.05	.01
	5404	.07	.06	.02	.02
	5405	.07	.04	.06	.01
	5406	.09	.09	.04	.03
	5407	.11	.19	.07	.08
	5408	.07	.17	.15	.02
	5409	.08	.08	.21	.02
	5410	.10	.08	.05	.03
	5413	.09	.06	.12	.01
	5414	.05	.04	.09	.02

[a] Analyses made by the Bureau of Soils, U. S. Dept. of Agr.

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Georgia[a]	6263	0.16	0.12	0.16	0.13
	6364	.09	.05	.09	.12
Kansas[a]	1217aA	.18	.09	Trace.	....
	1217aB	.54	.10	2.84	.66
	1217aC	.26	.11	Trace.	.36
	1217aD	.70	.13	3.23	.62
	5299	.53	.11	.17	....
Kentucky[a]	7565	.28	.03	.05	.06
	13715	.39	.05	.24	.40
	13716	.31	.05	.24	.43
	13717	.23	.05	.29	.37
	13718	.26	.04	.23	.41
	1059a	1.06	.25	.23	.51
Louisiana[a]	733	.71	.19	.54	....
	734	.76	.18	.66	....
Maryland[a]	132	.41	....	.44	.69
	5460	.38	.08	.21	.34
	5459	.91	.11	.11	.15
	5456	.44	.10	.11	.47
	5455	.89	.05	.15	.40
	5454	.86	.09	.14	.14
	1099	.46	.20	1.26	....
	749a	.15	.04	.09	....
	864a	.08	.04	.09	.03
Minnesota[a]	15355	.73	.24	6.45	....
	15356	.63	.17	13.83	....
	15357	.15	.24	4.22	....
	15358	.15	.15	1.07	....
	15359	.14	.23	1.03	....
	15360	.17	.13	.60	....
Mississippi[a]	7935	.31	.24	.83	1.22
Nebraska[a]	17205	.91	.19	2.35	1.22
	17208	.96	.26	1.95	.42
	17214	.99	.26	3.07	.65
	17221	.54	.29	2.35	.47
	2809	.10	.30	.24	.03
	6832	.08	.02	.19	.09
New Jersey[a]	1242a	1.20	.28	.24	....
	5685	1.09	1.25	1.27	3.23
Nevada[a]	17990	72	.12	1.45	1.23
	17993	.69	.20	1.81	1.60
	17996	.99	.17	1.86	1.42
	17999	.66	.20	1.56	1.31
	18002	1.07	.16	1.78	1.46
	18005	.73	.15	1.70	1.21
	18008	.92	.21	1.80	1.51
North Dakota[a]	6549	.92	.10	.92	1.37
Pennsylvania[a]	1119a	.35	.16	.08	....
		.30	.17	.09	....
State College	1283a	.46	.12	.31	.54
	1266a	.40	.11	.26	.47
	1268a	.47	.11	.23	.46
	1270a	.42	.12	.25	.41
	1273a	.47	.11	.25	.42
	1274a	.40	.01	.25	.45
	1276a	.44	.03	.26	.55
	1278a	.44	.13	.24	.52
	1280a	.26	.11	.33	.44
	1282a	.35	.16	.34	.43
	1284a	.49	.13	.29	.56
	1265a	.43	.11	.25	.55
	1267a	.38	.11	.23	.42
	1269a	.41	.12	.24	.45
	1271a	.42	.11	.24	.50
	1272a	.39	.14	.27	.50
	1275a	.40	.11	.26	.53
	1277a	.38	.13	.23	.49
	1279a	.30	.15	.36	.47
	1281a	.26	.12	.31	.38
South Carolina[a]	3961	.02	.76	.59	.26
Texas[a]	2165	.13	.02	.07	.06
	2167	.08	.02	.15	.16
	805a	.06	.03	.22	.09
		.02	.02	.27	.09
	790a	.82	....	7.25	1.17
	12481	1.64	.14	2.67	....
	12482	1.20	.10	6.88	....

[a] Analyses made by the Bureau of Soils, U. S. Dept. of Agr.

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Virginia[a]	1295a	1.02	0.16	0.14	....
	4004	.06	.30	.09	0.18
Washington[a]	6546	.57	.11	1.11	1.01
Wisconsin[a]	798a	1.51	.05	.37	....
California:[b]					
Eldorado County	1638	.55	.23	.52	.38
Stanislaus County	1901	.98	.05	.61	.51
	1900	.49	.05	.44	.34
Tulare County	1903	.97	.15	.79	1.22
	1904	.87	.05	.73	.64
Ventura County	1910	.84	.14	.74	1.27
Los Angeles County	1820	1.60	.31	2.73	2.87
	1908	.41	.23	1.95	2.04
	1906	1.18	.21	2.66	1.79
	1907	1.01	.15	2.49	1.75
Eldorado County	2214	.31	.15	.38	.69
Shasta County	2181	.40	.06	1.34	.67
Modoc County	2169	.41	.25	3.65	2.55
Glenn County	2291	.23	.22	1.53	.42
Yuba County	2403	.42	.20	.72	1.45
	2405	.42	.14	.97	1.83
Humboldt County	2319	.61	.30	.44	1.76
Mendocino County	2243	.95	.15	1.40	2.55
	2453	1.41	.28	1.09	2.35
Lake County	2301	.61	.08	2.51	1.37
	2295	.84	.12	2.34	.50
Contra Costa County	2454	.53	.07	4.50	1.83
Alameda County	1880	1.17	.19	1.38	2.68
	2430	.33	.07	.76	.76
San Luis Obispo County	2061	.67	.71	2.11	2.26
Ventura County	2273	.49	.06	.35	.89
Riverside County	2234	1.00	.16	1.50	1.64
San Diego County	1936	.18	.11	.47	.58
Riverside County	2470	.80	.14	2.69	.75
	2471	1.26	.21	2.71	2.20
San Diego County	2324	.76	.23	4.35	1.24
	2325	.74	.22	3.75	1.68
Florida,[c] Dade County	10	.0965	.0240	.0250	.0090
	14	.0043	.0240	.1275	.0612
	19	.0178	.0256	.0725	.0351
	18	Trace.	.0304	.5500	.0036
Lee County	1	.0164	2.5630	6.6050	.0290
	25	.0058	.0208	Trace.	.0299
	26	Trace.	.0496	.0725	.0198
	28	.0125	.0112	.0000	.0117
	59	.0024	.0128	.0700	.0261
De Soto County	4	.0212	.0160	.0750	.1125
	64	.0072	.0928	.0000	.0369
Brevard County	12	.0086	.0336	.2100	.0225
	13	.0111	.0192	.1075	.0099
	21	.0612	.0544	2.2325	.0207
	38	Trace.	.0416	.0400	.0090
	40	.0034	Trace.	.0000	.0634
	X	.0198	.0333	.1150	.0197
Osceola County	47	.0077	.0032	.0225	.0144
	49	.0073	.0096	.0150	.0252
	51	Trace.	.0144	.0600	.0234
Polk County	42	.0038	.0064	.0000	.0090
	43	Trace.	.2768	.0125	.0531
	44	Trace.	2.4000	.1125	.0990
	45	.0028	.2112	.0175	.0414
	55	Trace.	.0272	.0125	.0261
	57	Trace.	.0240	.0000	.0162
Hillsboro County	75	.0028	.3408	.2025	.0693
	116	.0023	.0880	.2650	.0072
Pasco County	73	.0048	.1360	.0250	.0405
Orange County	31	Trace.	.1328	.0275	.0369
	60	Trace.	.0816	.0000	.0270
	62	.0193	.0272	.0000	.0036
	Y	.0160	.1175	.0624	.0175
Volusia County	6	.0048	.0112	.0500	.0297
	8	.0164	.0577	.0225	.0279
	Z	.0208	.1660	.0526	.0145
Marion County	33	.0149	.2544	.1500	.0198

[a] Analyses made by the Bureau of Soils, U. S. Dept. of Agr.
[b] Ann. Rep. Cal. Agr. Expt. Sta., 1895-1897, 1901-1903.
[c] Buls. 43 and 68, Fla. Agr. Expt. Sta. (1897, 1903).

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
Florida—Continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Miami	1296	0.0135	0.0162	0.1740	0.0176
	1298	.0170	.0075	.1587	.0222
	1300	.0170	.0062	.0312	.0149
Boca Raton	1302	.0097	.0087	.0187	.0000
	1304	.0145	.0087	.0062	.0000
West Palm Beach	1306	.0140	.0087	.0087	.0000
	1308	.0048	.0100	.0037	.0000
	1310	.0097	.0087	.0062	.0062
	1312	.0145	.0137	.0287	.0156
Jensen	1314	.0061	.0120	.0000	.0095
	1316	.0073	.0056	.0112	.0049
	1318	.0061	.0087	.0087	.0056
Eldred	1320	.0110	.0431	.0862	.0511
	1322	.0134	.0106	.0137	.0000
St. Petersburg	1380	.0134	.0056	.0162	.0058
	1382	.0134	.0556	.0312	.0357
Oneco	1384	.0122	.0106	.0187	.0163
Punta Gorda	1386	.0170	.0187	.0850	.0171
	1388	.0110	.0050	.0475	.0144
Orlando	1390	.0158	.0250	.0350	.0432
Key	1411	.2963	.9459	4.7259	1.5738
Idaho:[a]					
Kootenai County	9	....	Trace.	1.32	.03
	20	....	.45	.94	1.16
Latah County	17	.59	.49	2.80	.51
	19	.61	1.57	.13	.19
Shoshone County	5	.04	.35	.78	.72
Nez Perce County	31	.034	.25	3.75	.91
Idaho County	13	.04	.62	1.49	2.52
	14	.40	.01	1.44	.34
	15	1.92	.01	.64	.22
Canyon County	1	....	.31	2.70	.58
	6	....	1.20	.69	1.60
	7	....	.09	Trace.	.57
	8	....	.19	.65	.38
Bingham County	21	1.16	1.39	.07	.31
	22	1.22	.47	2.59	.29
	23	1.28	.41	2.15	.14
	24	.99	1.16	2.08	1.25
	25	1.04	.21	.06	1.09
Bear Lake County	26	1.44	.31	1.43	.37
	27	.72	.19	3.94	3.15
	29	1.12	.05	.59	3.15
	30	.72	.94	5.92	1.24
Cassia County	4	.775	.183	1.971	1.387
	5	.695	.137	1.870	1.322
Cœur d'Alene	7	.440	.188	.533	1.290
	9	.467	.205	.432	1.527
Nez Perce County	11	.459	.188	.507	.906
American Ridge	12	.684	.157	.557	.997
Latah County	13	.673	.131	.722	1.019
	14	.557	.206	.767	.902
Lewiston	15	.526	.148	.872	1.150
Moscow	16	.563	.192	.939	.886
	18	.677	.176	.999	.766
Boise	20	.789	.237	1.567	1.090
	21	.896	.184	.893	1.006
	22	.459	.141	.465	.535
	23	.572	.143	.780	.831
Louisiana:[b]					
Calhoun	1	.023	.037	.085	.018
	2	.029	.048	.145	.074
	3	.011	.021	.027	.027
	5	.008	.011	.009	.011
Monroe	7	.069	.072	.128	.180
	9	.023	.007	.040	.036
Mississippi:[c]					
Agricultural College	48	.125	.148	.45	.32
	50	.153	.187	.43	.55
	49	.122	.092	.161	.12
	51	.126	.114	.307	.47
	52	.303	.204	.400	.68
	53	.104	.156	.770	.60
	54	.127	.233	.370	.47
	55	.132	.149	.610	.60

[a] Buls. 9 and 28, Idaho Agr. Expt. Sta. (1894, 1901).
[b] Special Rep. on the Geology and Agriculture of the Hills of La., Pt. I. La. Agr. Expt. Sta., 1892.
[c] Ann. Rep. Miss. Agr. Expt. Sta., 1895 and 1898–99; Bul. 65, Miss. Agr. Expt. Sta. (1900).

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
Mississippi—Continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Agricultural College	56	0.117	0.182	0.440	0.60
	57	.097	.185	.64	.56
	58	.131	.102	.54	.39
	59	.150	.147	.83	.79
	60	.111	.096	.40	.53
	61	.145	.181	.63	.40
	62	.116	.118	.39	.12
	162	.12	.08	.14	.10
	163	.06	.08	.22	.06
Union County	606	.31	.089	.86	.061
Jackson County	692	.050	.027	.16	.072
	694	.056	.015	.23	.064
	695	.080	.004	.20	.028
Chickasaw County	888	.10	.26	.27	.22
Covington County	1522	.09	.184	.302	.318
	1523	.08	.100	.280	.126
Noxubee County	1524	.18	.24	4.91	.144
Oktibbeha County	1536	.25	.097	.47	.38
Tallahatchie County	1538	.46	.257	.94	.25
Hinds County	1544	.10	.07	.66	.36
Oktibbeha County	1572	.22	.192	1.85	.302
Holmes County	1696	.24	.190	.35	.08
Crystal Springs	928	.07	.07	.175	....
Coffeeville	400	.20	.09	.27	.24
	401	.18	.09	.22	.28
	402	.09	.06	.15	.17
	403	.17	.08	.19	.25
	404	.14	.06	.19	.19
Yazoo City	421	.365	.127	2.14	.11
Como	75	.143	.27	.88	.023
	76	.147	.232	.084	.033
Elizabeth	269	.55	.16	.34	.20
Oktibbeha County	617	.300	.144	1.88	....
	620	.280	.093	5.90	....
	621	.360	.262	1.03	....
	622	.210	.108	.380	....
	583	.380	.247	.315	....
	594	.200	.108	.230	....
	595	.420	.229	.190	....
	597	.165	.147	.32	....
	585	.460	.300	.630	....
Wilkinson County	1026	.166	.033	.080	....
Oktibbeha County	833	.337	.079	.185	....
Jones County	1013	.208	.024	.111	....
Kemper County	926	.076	.110	.192	....
	928	.465	.156	1.68	....
	929	.185	.072	.980	....
	931	.263	.053	.535	....
Noxubee County	932	.442	.188	.960	....
	933	.148	.084	.210	....
	935	.201	.090	.325	....
	937	.218	.085	.985	....
	939	.478	.189	.156	....
	940	.463	.121	.145	....
	941	.426	.121	1.130	....
	942	.400	.263	1.18	....
	943	.500	.302	15.57	....
	944	.509	.321	5.24	....
	945	.574	.296	5.15	....
	946	.450	.105	.945	....
	948	.360	.046	.990	....
	949	.372	.105	.485	....
	951	.245	.079	.325	....
Lowndes County	1153	.358	.111	3.56	....
	1154	.387	.140	3.71	....
	1155	.283	.093	.315	....
	1157	.268	.123	.360	....
Oktibbeha County	581	.39	.096	.11	....
	584	.92	.57	1.06	....
	586	.210	.115	.235	....
	593	.177	.14	.180	....
	622	.21	.106	.38	....
	1106	.491	.328	2.69	....
	1107	.470	.143	.265	....
	1108	.423	.274	2.25	....
	1117	.360	.086	.950	....
	1118	.480	.121	12.52	....
	1119	.181	.105	.117	....

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
Mississippi—Continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Oktibbeha County	1121	0.152	0.097	0.175	....
	1122	.150	.083	.100	....
	1111	.215	.055	.800	....
	1113	.305	.070	1.06	....
	1280	.276	.075	.960	....
	1124	.454	.332	.260	....
	1126	.177	.119	170	....
	1114	.398	.114	1.20	....
	1115	.262	.080	.800	....
	1158	.331	.188	.940	....
Clay County	1159	.193	.051	.650	....
	1161	.395	.184	1.53	....
	1162	.369	.244	1.24	....
	1163	.302	.207	1.36	....
	1165	.258	.113	.430	....
Monroe County	1168	.502	.191	1.82	....
	1169	.364	.109	1.11	....
	1172	.401	.174	6.26	....
	1174	.208	.089	1.59	....
	1175	.370	.153	.680	....
Chickasaw County	1178	.305	.115	1.06	....
	1179	.198	.036	.615	....
	1180	.258	.054	.890	....
	1181	.402	.140	5.80	....
	1182	.135	.047	.160	....
	1274	.189	.056	.110	....
	1276	.262	.064	.150	....
Lee County	1184	.385	.160	1.20	....
	1185	.340	.134	.815	....
	1186	.321	.210	1.61	....
	1187	.216	.210	3.27	....
	1189	.297	.237	1.27	....
	1190	.395	.194	1.47	....
	1191	.157	.068	.235	....
	1193	.402	.185	.940	....
	1194	.269	.118	.470	....
	1200	.200	.083	.500	....
	1202	.250	.076	.340	....
	1204	.096	.032	.053	....
	1206	.179	.253	9.63	....
	1209	.129	.055	.160	....
	1213	.086	.025	.030	....
Prentiss County	1211	.220	.090	.510	....
	1217	.098	.036	.190	....
	1219	.103	.043	.120	....
	1221	.102	.065	.120	....
	1223	.321	.329	11.93	....
	1225	.226	.129	.810	....
	1227	.273	.174	.340	....
	1229	.105	.009	.070	....
	1234	.088	.018	.072	....
	1250	.089	.027	.205	....
	1253	.359	.092	1.32	....
	1254	.122	.051	.160	....
	1256	....	.114	1.05	....
	1257	.565	.140	.830	....
Alcorn County	1241	.147	.071	.235	....
	1245	.185	.051	.245	....
	1248	.157	.050	.140	....
Union County	1261	.276	.048	.190	....
	1263	.187	.035	.160	....
	1265	.170	.038	.190	....
	1266	.203	.052	.140	....
	1268	.258	.093	.205	....
	1030	.190	.024	.110	....
Pontotoc County	1269	.336	.167	.142	....
	1272	.333	.094	.106	....
Alcorn County	1236	.178	.072	.145	....
Madison County	625	.215	.062	.29	....
	629	.20	.076	.22	....
	633	.170	.083	.17	....
	879	.250	.061	.120	....
	881	.257	.040	.165	....
	883	.396	.068	.145	....
	884	.180	.042	.145	....
	876	.326	.022	.300	....
	886	.225	.039	.265	....

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
Mississippi—Continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Leake County	890	0.281	0.018	0.110	....
	892	.160	.019	.110	....
	894	.165	.022	.025	....
	895	.093	.016	.05	....
Attala County	897	.190	.030	.115	....
	898	.229	.044	.210	....
	900	.160	.047	.130	....
	902	.105	.013	.050	....
Choctaw County	904	.246	.075	.160	....
	905	.177	.024	.050	....
	906	.197	.037	.105	....
Carroll County	958	.363	.080	.120	....
	960	.276	.188	.135	....
	961	.222	.104	.160	....
	963	.298	.051	.100	....
	965	.408	.078	.110	....
	967	.436	.090	.120	....
	969	.170	.050	.125	....
Yalobusha County	971	.180	.023	.015	....
	973	.311	.044	.065	....
	974	.212	.053	.140	....
	975	.223	.063	.145	....
Panola County	976	.293	.102	.170	....
	977	.335	.168	.260	....
	978	.333	.117	.130	....
	979	.323	.070	.190	....
	981	.426	.064	.170	....
	983	.322	.064	.125	....
	985	.373	.089	.185	....
	988	.304	.135	.120	....
Tate County	991	.183	.066	.190	....
	994	.241	.055	.140	....
	996	.262	.064	.220	....
	997	.303	.071	.165	....
	1000	.43	.097	.050	....
	1001	.26	.069	.150	....
Marshall County	1003	.253	.041	.300	....
	1007	.360	.083	.225	....
	1008	.252	.079	.275	....
Amite County	1021	.125	.055	.095	....
	1023	.17	.067	.175	....
	1025	.242	.057	.125	....
	1026	.166	.033	.08	....
Hinds County	871	.168	.040	.190	....
	873	.182	.057	.210	....
	875	.277	.050	.105	....
Neshoba County	834	.170	.052	.075	....
	836	.247	.087	.165	....
	838	.163	.045	.080	....
Scott County	853	.270	.097	.235	....
	855	.210	.044	.10	....
	856	.309	.058	.20	....
	848	.190	.025	.095	....
	849	.202	.066	.285	....
	850	.150	.049	.135	....
Leake County	844	.189	.050	.205	....
	846	.165	.038	.170	....
Scott County	852	.130	.082	.085	....
Neshoba County	954	.563	.117	.360	....
Copiah County	801	.203	.064	.15	....
	803	.223	.058	.075	....
	805	.297	.064	.175	....
	807	.190	.061	.175	....
	809	.170	.040	.140	....
	810	.286	.047	.145	....
	811	.263	.068	1.20	....
	813	.173	.05	.070	....
	816	.300	.107	.255	....
	818	.196	.149	.225	....
	820	.233	.081	.215	....
	822	.200	.040	.155	....
	823	.277	.065	.120	....
	824	.253	.050	.285	....
	825	.251	.060	.100	....
	826	.262	.077	.150	....
	827	.128	.064	.095	....
	828	.134	.047	.115	....
	830	.199	.060	.130	....
	831	.264	.064	.125	....

Chemical composition of the soils of the United States—Continued.

State or Territory.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia MgO).
Mississippi—Continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Jones County	832	0.132	0.036	0.125	....
	1010	.123	.046	.20	....
	1012	.160	.035	.15	....
Harrison County	674	.098	.033	.18	....
Winston County	913	.160	.044	.155	....
	915	.145	.055	.160	....
Kemper County	917	.140	.074	.068	....
	919	.199	.060	.130	....
Winston County	911	.133	.022	.100	....
Neshoba County	921	.090	.028	.020	....
Kemper County	923	.141	.019	.070	....
	925	.345	.029	.170	....
Scott County	858	.129	.013	.195	....
	859	.255	.029	.725	....
Rankin County	861	.290	.052	.220	....
	862	.194	.040	.185	....
	864	.240	.080	.115	....
	865	.230	.097	.125	....
	867	.193	.062	.125	....
	869	.115	.057	.15	....
Washington County	269	.55	.16	.34	....
Bolivar County	676	.46	.17	.126	....
	677	6.87	.192	.92	....
	678	6.92	.195	.89	....
	679	.941	.216	.97	....
Coahoma County	700	.54	.092	.40	....
	701	.54	.14	.41	....
	702	.84	.134	.59	....
	703	.36	.115	.34	....
Jasper County	658	.415	.118	.372	....
	659	.50	.109	.245	....

ALABAMA.—Four samples have been reported upon from this State, the range in composition being for potash 0.149 to 0.903 per cent, phosphoric acid 0.017 to 0.15 per cent, lime 0.039 to 0.289 per cent, and magnesia 0.01 to 0.633 per cent.

ARIZONA.—Twenty-two samples have been reported upon from this State, the range in composition being for potash 0.472 to 1.959 per cent, for phosphoric acid 0.031 to 0.244 per cent, lime 0.579 to 8.67 per cent, and magnesia 0.66 to 3.086 per cent.

ARKANSAS.—Six samples have been reported upon from this State, the range in composition being for potash 0.15 to 0.36 per cent, phosphoric acid 0.07 to 0.16 per cent, lime 0.07 to 0.15 per cent, and magnesia 0.14 to 0.29 per cent.

CALIFORNIA.—One hundred and fifteen samples have been reported upon from this State, the range in composition being for potash 0.09 to 1.84 per cent, phosphoric acid 0.02 to 0.71 per cent, lime 0.113 to 13.94 per cent, and magnesia 0.16 to 16.97 per cent.

COLORADO.—Twenty-nine samples have been reported upon from this State, the range in composition being for potash 0.14 to 1.27 per cent, for phosphoric acid 0.06 to 0.36 per cent, lime 0.40 to 6.00 per cent, and magnesia 0.13 to 1.61 per cent.

CONNECTICUT.—Only one sample has been reported upon from this State, containing 0.23 per cent potash, 0.22 per cent phosphoric acid, 0.32 per cent lime, and 0.78 per cent magnesia.

District of Columbia.—Four samples have been reported upon from the District of Columbia, the range in composition being for potash 0.29 to 0.53 per cent, phosphoric acid 0.05 to 0.14 per cent, lime 0.26 to 0.57 per cent, and magnesia 0.01 to 0.19 per cent.

Florida.—Eighty-eight samples have been reported upon from this State, the range in composition being for potash 0.0023 to 0.2963 per cent, phosphoric acid 0.0032 to 2.563 per cent, lime 0.0037 to 7.60 per cent, and magnesia 0.001 to 1.5758 per cent.

Georgia.—Two samples have been reported upon from this State, the range in composition being for potash 0.09 to 0.16 per cent, phosphoric acid 0.05 to 0.12 per cent, lime 0.09 to 0.16 per cent, and magnesia 0.12 to 0.16 per cent.

Idaho.—Thirty-seven samples have been reported upon from this State, the range in composition being for potash 0.034 to 1.92 per cent, phosphoric acid 0.01 to 1.57 per cent, lime 0.06 to 5.92 per cent, and magnesia 0.03 to 3.15 per cent.

Illinois.—Five samples have been reported upon from this State, the range in composition being for potash 0.156 to 0.580 per cent, phosphoric acid 0.066 to 0.185 per cent, lime 0.21 to 1.455 per cent, and magnesia 0.218 to 0.989 per cent.

Indiana.—Thirteen samples have been reported upon from this State, the range in composition being for potash 0.181 to 0.68 per cent, phosphoric acid 0.041 to 1.01 per cent, lime 0.37 to 1.387 per cent, and magnesia 0.45 to 0.771 per cent.

Iowa.—Two samples have been reported upon from this State, the range in composition being for potash 0.337 to 0.365 per cent, phosphoric acid 0.093 to 0.137 per cent, lime 0.790 to 1.185 per cent, and magnesia 0.585 to 0.662 per cent.

Kansas.—Seven samples have been reported upon from this State, the range in composition being for potash 0.18 to 0.766 per cent, phosphoric acid 0.089 to 0.13 per cent, lime 0.17 to 3.23 per cent, and magnesia 0.36 to 0.66 per cent.

Kentucky.—Ninety-two samples have been reported upon from this State, the range in composition being for potash 0.09 to 1.06 per cent, phosphoric acid 0.015 to 1.755, lime 0.05 to 1.725, and magnesia 0.08 to 0.52 per cent.

Louisiana.—Eighteen samples have been reported upon from this State, the range in composition being for potash 0.008 to 1.94 per cent, phosphoric acid 0.007 to 0.193 per cent, lime 0.009 to 2.06 per cent, and magnesia 0.011 to 2.547 per cent.

Maine.—Only one sample has been reported upon from this State, containing 0.14 per cent potash, and 0.17 per cent phosphoric acid.

Maryland.—Fourteen samples have been reported upon from this State, the range in composition being for potash 0.08 to 0.91 per cent, phosphoric acid 0.04 to 0.50 per cent, lime 0.09 to 1.26 per cent, and magnesia 0.03 to 0.69 per cent.

MASSACHUSETTS.— Only one sample has been reported upon from this State, containing 0.153 per cent potash, 0.144 per cent phosphoric acid, 0.525 per cent lime, and 0.558 per cent magnesia.

MICHIGAN.—Forty samples have been reported upon from this State, the range in composition being for potash 0.118 to 2.12 per cent, phosphoric acid 0.01 to 0.88 per cent, lime 0.20 to 6.09 per cent, and magnesia 0.12 to 1.59 per cent.

MINNESOTA.—One hundred and sixty-six samples have been reported upon from this State, the range in composition being for potash 0.08 to 1.16 per cent, phosphoric acid 0.04 to 2.61 per cent, lime 0.11 to 14.0 per cent, and magnesia 0.10 to 6.12 per cent.

MISSISSIPPI.—Two hundred and seventy-six samples have been reported upon from this State, the range in composition being for potash 0.05 to 6.92 per cent, phosphoric acid 0.004 to 0.57 per cent, lime 0.015 to 15.57 per cent, and magnesia 0.023 to 1.22 per cent.

MISSOURI.—Eight samples have been reported upon from this State, the range in composition being for potash 0.272 to 2.57 per cent, phosphoric acid 0.06 to 0.121 per cent, lime 0.405 to 0.630 per cent, and magnesia 0.21 to 0.55 per cent.

MONTANA.—Two samples have been reported upon from this State, the range in composition being for potash 0.731 to 0.747 per cent, phosphoric acid 0.176 to 0.185 per cent, lime 0.87 to 0.97 per cent, and magnesia 0.907 to 1.105 per cent.

NEBRASKA.—Fifteen samples have been reported upon from this State, the range in composition being for potash 0.041 to 0.99 per cent, phosphoric acid 0.02 to 1.421 per cent, lime 0.19 to 3.07 per cent, and magnesia 0.03 to 1.22 per cent.

NEVADA.—Forty-eight samples have been reported upon from this State, the range in composition being for potash 0.016 to 3.34 per cent, phosphoric acid 0.019 to 2.292 per cent, lime 0.80 to 17.831 per cent, and magnesia 0.17 to 8.404 per cent.

NEW HAMPSHIRE.—Five samples have been reported upon from this State, the range in composition being for potash 0.64 to 1.06 per cent, phosphoric acid 0.05 to 0.36 per cent, lime 0.63 to 0.77 per cent, and magnesia 0.53 to 0.74 per cent.

NEW JERSEY.—Two samples have been reported upon from this State, the range in composition being for potash 1.09 to 1.20 per cent, phosphoric acid 0.28 to 1.25 per cent, and lime 0.24 to 1.27 per cent.

NEW YORK.—Sixteen samples have been reported upon from this State, the range in composition being for potash 0.246 to 1.04 per cent, phosphoric acid 0.01 to 0.202 per cent, lime 0.125 to 1.873 per cent, and magnesia 0.274 to 1.94 per cent.

NORTH CAROLINA.—Two samples have been reported upon from this State, the range in composition being for potash 0.02 to 0.161 per cent, phosphoric acid 0.016 to 0.02 per cent, lime 0.07 to 0.24 per cent, and magnesia 0.02 to 0.047 per cent.

NORTH DAKOTA.—Twenty-five samples have been reported upon from this State, the range in composition being for potash 0.18 to 0.96 per cent, phosphoric acid 0.10 to 0.40 per cent, lime 0.32 to 14.67 per cent, and magnesia 0.07 to 1.37 per cent.

OHIO.—Fifty-seven samples have been reported upon from this State, the range in composition being for potash 0.04 to 0.64 per cent, phosphoric acid 0.064 to 0.80 per cent, lime 0.07 to 0.68 per cent, and magnesia 0.09 to 0.76 per cent.

OKLAHOMA.—Three samples have been reported upon from this State, the range in composition being for potash 0.32 to 0.80 per cent, phosphoric acid 0.04 to 0.06 per cent, lime 0.44 to 0.95 per cent, and magnesia 0.16 to 0.21 per cent.

OREGON.—One hundred and thirty-six samples have been reported upon from this State, the range in composition being for potash 0.02 to 1.85 per cent, phosphoric acid 0.01 to 2.30 per cent, lime 0.10 to 14.36 per cent, and magnesia 0.01 to 3.36 per cent.

PENNSYLVANIA.—Twenty-four samples have been reported upon from this State, the range in composition being for potash 0.26 to 0.67 per cent, phosphoric acid 0.01 to 0.265, lime 0.08 to 0.61, and magnesia 0.38 to 2.05 per cent.

RHODE ISLAND.—Seven samples have been reported upon from this State, the range in composition being for potash 0.124 to 0.184 per cent, phosphoric acid 0.029 to 0.127 per cent, lime 0.252 to 1.295 per cent, and magnesia 0.209 to 1.141 per cent.

SOUTH CAROLINA.—Eleven samples have been reported upon from this State, the range in composition being for potash 0.02 to 0.541 per cent, phosphoric acid 0.011 to 0.76 per cent, lime 0.019 to 0.59 per cent, and magnesia 0.003 to 0.811 per cent.

SOUTH DAKOTA.—Two samples have been reported upon from this State, the range in composition being for potash 0.365 to 0.39 per cent, phosphoric acid 0.147 to 0.153 per cent, lime 0.665 to 0.710 per cent, and magnesia 0.585 to 0.628 per cent.

TENNESSEE.—One hundred and forty-four samples have been reported upon from this State, the range in composition being for potash 0.06 to 0.91 per cent, phosphoric acid 0.01 to 1.70 per cent, lime 0.02 to 2.25 per cent, and magnesia 0.085 to 0.96 per cent.

TEXAS.—One hundred and seventeen samples have been reported upon from this State, the range in composition being for potash 0.01 to 11.37 per cent, phosphoric acid 0.008 to 0.60 per cent, lime 0.02 to 34.91 per cent, and magnesia 0.01 to 4.01 per cent.

Utah.—Fifty-five samples have been reported upon from this State, the range in composition being for potash 0.046 to 2.69 per cent, phosphoric acid 0.103 to 0.42 per cent, lime 0.37 to 22.54 per cent, and magnesia 0.07 to 2.52 per cent.

Virginia.—Two samples have been reported upon from this State, the range in composition being for potash 0.06 to 1.02 per cent, phosphoric acid 0.16 to 0.30 per cent, and lime 0.09 to 0.14 per cent.

Washington.—One hundred and ninety-four samples have been reported upon from this State, the range in composition being for potash 0.003 to 9.178 per cent, phosphoric acid 0.019 to 0.543 per cent, lime 0.005 to 36.009 per cent, and magnesia 0.005 to 4.83 per cent.

West Virginia.—Fourteen samples have been reported upon from this State, the range in composition being for potash 0.243 to 0.888 per cent, phosphoric acid 0.088 to 0.211 per cent, and lime 0.055 to 0.451 per cent.

Wisconsin.—Thirteen samples have been reported upon from this State, the range in composition being for potash 0.08 to 1.81 per cent, phosphoric acid 0.05 to 0.27 per cent, lime 0.37 to 1.82 per cent, and magnesia 0.412 to 2.08 per cent.

Wyoming.—Nine samples have been reported upon from this State, the range in composition being for potash 0.52 to 0.73 per cent, phosphoric acid 0.12 to 0.28 per cent, lime 0.64 to 6.63 per cent, and magnesia 0.14 to 3.21 per cent.

Chemical composition of the soils of Great Britain and Ireland.

ENGLAND.

County.	Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Dorset[a]	Alluvium	38	0.46	0.42	3.84	0.48
		62	.22	.23	1.31	.11
		41	.81	.46	1.09	.26
	Gravel	36	.22	.32	.71	.45
		37	.33	.28	.64	.27
		63	.18	.26	.11	.04
		64	.17	.20	.10	.06
	Bagshot beds	83	.19	.18	.37	.02
		30	.13	.25	1.43	.34
		40	.18	.20	.80	.17
		65	.13	.12	.08	.06
	London clay	80	.23	.32	.37	.12
		12	.22	.47	1.26	.31
		68	.20	.15	.36	.07
	Reading beds	81	.27	.33	.66	.27
		11	.27	.40	1.57	.68
		67	.24	.21	.65	.07
		61	.06	.11	.33	.02
	Junction Reading beds and chalk.	39	.24	.42	1.80	.27
	Chalk	15	.25	.30	41.00	.83
		71	.27	.29	38.78	.65
		99	.19	.78	31.50	.53
		95	.29	.47	31.05	.11

[a] Fifth Annual Report on the Soils of Dorset, University College, Reading, 1903. In the original paper the results are expressed as lime carbonate and lime other than carbonate; these have been recalculated to give CaO content.

Chemical composition of the soils of Great Britain and Ireland—Continued.

ENGLAND—Continued.

County.	Description and locality.	Original sample No.	Potash (K_2O.)	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Dorset	Chalk	51	0.20	0.33	31.90	0.27
		94	.22	.49	14.22	.15
		35	.28	.24	5.69	.71
		50	.39	.36	35.60	.27
		16	.59	.33	33.40	.71
		72	.50	.27	9.48	.43
		49	.20	.31	2.09	.19
		21	.39	.25	1.71	.39
		100	.38	.51	1.38	.47
		1	.17	.44	.88	.41
		98	.47	.36	.98	.39
		96	.42	.31	1.30	.06
		97	.57	.26	.34	.28
	Greensand	79	.35	.37	.43	.08
		47	.81	.60	.92	.46
		48	.74	.79	7.12	1.00
		2	.40	.23	2.18	.59
	Junction greensand and marlstone.	31	.27	.32	1.55	.27
		25	.29	.28	.85	.68
	Wealden beds	33	.31	.31	1.01	.41
		32	.25	.44	1.36	.34
		84	.24	.29	.65	.32
		69	.36	.28	.96	.11
		22	.31	.50	.92	.37
	Purbeck beds	27	.34	.29	1.82	.48
	Portland stone	66	.46	.43	.51	.07
	Kimmeridge clay	3	.30	.15	2.10	.55
		20	.4	.6	2.10	.50
		42	.47	.89	2.23	.09
		85	.61	.38	2.47	.43
		86	.81	.24	1.87	.51
		87	.95	.34	1.76	.42
		88	.92	.50	1.18	.51
	Coral rag	19	.38	.31	.67	.96
		77	.63	.32	6.34	.54
		82	.39	.47	10.53	.53
		89	.53	.60	18.75	.60
		8	.27	.40	26.75	.36
		57	.68	.35	2.03	.69
		58	.49	.32	12.09	.20
	Calcareous grit	9	.25	.31	.80	.63
	Oxford clay	73	.79	.38	1.88	.21
		34	.21	.38	.81	.55
		60	.91	.34	2.04	.47
		59	.53	.23	.60	.35
		52	.73	.33	1.70	.50
		53	.49	.32	.59	.25
		29	.34	.25	.60	.32
		4	.46	.45	2.99	.38
	Cornbrash	10	.26	.49	3.16	.64
		76	.50	.45	6.29	.22
		28	.23	.29	6.88	.46
	Fuller's earth	18	.41	.45	.99	1.06
		23	.17	.26	.77	.57
		56	.66	.27	.91	.35
		46	.89	.30	1.09	.53
		90	.80	.31	4.50	.82
		26	.53	.17	8.28	.01
	Inferior oolite	91	.52	.64	4.80	.93
		13	.50	.37	11.64	.29
	Junction inferior oolite and Midford sands.	14	.31	.34	2.44	.60
	Midford sands	55	.38	.36	.77	.48
		54	.38	.25	.45	.44
		45	.44	.38	.58	.41
		5	.33	.49	.31	.39
		92	.26	.60	.42	.29
	Junction Midford sands and marlstone.	6	.21	.31	1.34	.41
		43	.57	.32	1.39	.10
	Marlstone	7	.36	.49	.59	.38
		70	.30	.63	.65	.02
		75	.76	.33	.80	.43
		78	.58	.47	2.44	.61

Chemical composition of the soils of Great Britain and Ireland—Continued.

ENGLAND—Continued.

County.	Description and locality.	Original sample No.	Potash (K_2O.)	Phosphoric acid (P_2O^5).	Lime (CaO).	Magnesia (MgO).
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Dorset	Junction marlstone and lower Lias.	24	0.27	0.29	0.72	0.38
		44	.69	.35	.95	.39
	Lower Lias	17	.32	.40	2.28	.16
		74	.65	.51	1.14	.84
		93	.51	.53	.96	.55
Essex [a]	Birch		.38	.10	.57	
	Bulvan		.32	.10	.83	
	Burnham		.17	.18	1.78	
	Hedingham		.53	.16	1.18	
	Gosfield		.14	.14 .24	.63	
	Orsett		.12	.08	.36	
	Ramsden		.15	.22	.92	
	Roxwell		.79	.20	5.96	
	Saffron Walden		.34	.11	3.85	
			.41	.10	5.80	
			.48	.09	7.75	
	Tendring		.20	.16	.29	
	Thaxted		.18	.13	.85	
	St. Osyth		.16	.09	1.63	
	Yeldham		.52	.15	1.64	
Cambridge [b]	Hatley plot	3	.85	.39	.88	
	Joint rotation	9	.64	.22	.90	
	Burgoyn's (Univ. farm):					
	Fields 11-13		.625	.083	2.20	
	Fields 14-15		.559	.139	2.15	
	Fields 16-17		.58	.22	.76	
	Fields 18-19		.575	.091	.90	
	Bowlder clay:					
	Above Gault	14	.948	.14	3.95	.285
	Above Green sand	19	.785	.113	.78	.28
	Above Gault	20	.994	.107	1.22	.35
	Above Grey chalk	21	.963	.102	1.325	.60
	Gault soils	3	1.14	.14	3.87	.29
		7	1.143	.127	7.28	.15
		8	1.13	.097	4.74	.215
	Kimeridge clay soils	12	1.13	.147	.425	.134
		15	1.00	.098	.515	.18
		17	1.58	.093	2.425	.155
	Ampthill clay soils	6	.655	.096	.48	.145
	Oxford clay soils	10	1.06	.118	.323	.215
		11	1.11	.145	.322	.47
		22	1.09	.138	.308	.25
	Lower green sand soils	5	.236	.204	.065	.06
		23	.278	.259	.085	.125
		18	.47	.197	.34	.24
		9	.443	.169	.26	.17
		6	.47	.146	.15	.14
Lincolnshire [c]	Peaty matter from the fens.			.25	2.23	
	Fen soil	I	.42	.26	1.44	.28
		II	.43	.21	1.50	.34
		III	.28	.16	1.02	.42
	Marsh soil	I	.16	.16	2.16	.40
		II	.20	.21	2.12	.28
	Farm near Crowland	I	.08	.77	1.20	.30
		II	.07	1.02	1.00	.50
		III	.08	1.24	.87	.13
		IV	.11	1.20	1.24	.21
		V	.08	.68	1.09	.39
		VI	.09	1.23	2.00	.40

[a] Dymond, The Essex Field Experiments, 1896-1901, Part I. Compiled for the Essex Technical Instruction Committee.

Jour. Essex Tech. Laboratories, 3, 163 (1897).

Dymond and Bull, the Essex Field Experiments, 1896-1903, No. 2.

Guide to Experiments at Univ. Farm and other Centers in the Eastern Counties, Cambridge University, 1907.

[b] Guide to Experiments at University Farm and other Centers in the Eastern Counties, Cambridge University, 1907.

Foreman, Journal Agricultural Science, 2, 161 (1907).

[c] E. W. Bell, Chemical News, 68, 191 (1893), used HCl (S. G. 1.16).

R. H. Wilson, Chemical News, 70, 153 (1894).

Chemical composition of the soils of Great Britain and Ireland—Continued.

ENGLAND—Continued.

County.	Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesi (MgO).
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Northumberland [a]	Cockle Park (unmanured plot).	1	0.283	0.106	0.306	....
	Miniature Farms	9	.244	.087	.265	....
		1	.04	.12	....	....
		2	.04	.11	....	....
		3	.04	.13	....	....
		4	.05	.13	....	....
		5	.04	.13	....	....
		6	.05	.12	....	....
	Hanging Leaves	265	.49	.06	.43	....
	Castle Steads	267	.31	.07	.25	....
	Davy Houses	266	.20	.08	.27	....
	East Tower Hill	....	.06	.17	....	....
	Peepy	....	.144 .114	.034	.48	....
	Whitefield	....	.072	.115	.45	....
	Kimblesworth	355	.27	.07	.33	....
	Cockle Park:					
	Tower Hill	....	.44	.12	.79	....
	Back House	....	.263	.097	.286	....
	Tree Field	....	.50	.07	.69	....
	Pallace Leas Field plot	1	.36	.10	.44	....
		2	.40	.08	.44	....
		6	.33	.06	.39	....
		8	.28	.06	.37	....
		12	.39	.06	.55	....
		13	.30	.05	.42	....
Northampton [b]	Cransley plot	1	.54	.116	.60	....
		2	.57	.145	.67	....
		3	.59	.08	.53	....
		4	.66	.155	.62	....
		5	.50	.139	.45	....
		6	.54	.133	.58	....
		7	.49	.142	.79	....
		8	.50	.113	.45	....
		9	.65	.112	.84	....
		10	.65	.122	.76	....
Isle of Ely [c]	Black soils:					
	White Fen Benwick	....	.604	.306	2.95	....
	Littleport Fen	....	.559	.284	4.39	....
	Wryde	....	.458	.432	2.54	....
	Loam, Wisbech Fen	....	.602	.383	3.54	....
	Clays, Wryde	....	.532	.264	.764	....
			1.276	.374	1.48	....
	Silts, Wryde	....	.392	.224	3.19	....
	Silts, Needham	....	.281	.245	1.58	....
			.288	.192	1.57	....
Cheshire [d]	....	1	.30	.10	.54	....
		2	.41	.30	.60	....
Norfolk [e]	Saxlingham	5	.09	.082	.47	....
	Stanhoe	7	.112	.057	1.39	....
	Trowse plot	3	.13	.16	1.43	....
Suffolk [f]	Bramford	....	.19	.18	2.18	0.27
	Saxmundham	....	.71	.248	1.59	....
Durham [g]	Grange Hill plot	116	.07	.13	....	....
	Shield Ash plot	1	.35	.09	.54	....
		11	.47	.13	.81	....

[a] Somerville Agricultural Experiments, 5 years' work at the Northumberland County Demonstration Farm, 1902, pp. 62 and 167.
Gilchrist, Bulletin 4, Armstrong College, Newcastle upon Tyne.
Ninth Annual Report on Experiments, Counties of Cumberland, Durham, and Northumberland, 1900.
Gilchrist, Bulletin 8, County Agricultural Experiment Station, Newcastle upon Tyne.

[b] The Improvement of Poor Pastures, Report on an Experiment at Cransley, Northamptonshire, in seasons 1901, 1902, and 1903, Cambridge University.

[c] First Annual Report of Experiments, 1897, Cambridge, and Counties Agricultural Education Scheme.
Guide to Experiments at University Farm and other Centers in the Eastern Counties, Cambridge, 1907.

[d] Yearbook College of Agriculture and Horticulture, Holmes Chapel, Cheshire, 1904.

[e] Guide to Experiments at University Farm and other centers in the Eastern Counties, Cambridge University, 1907.

[f] Report on Experiments at Bramford and Saxmundham.

[g] Sixth Annual Report on Experiments in Counties of Cumberland, Durham, and Northumberland, 1897.
Tenth Annual Report on Experiments in Counties of Cumberland, Durham, and Northumberland, 1901.

Chemical composition of the soils of Great Britain and Ireland—Continued.

ENGLAND—Continued.

County.	Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid. (P_2O_5).	Lime (CaO).	Magnesia (MgO).
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Cumberland[a]	Rose Bank plot............	497	0.37	0.05	0.27	....
		499	.33	.05	.28	....
		501	.30	.05	.25	....
Hampshire[b]	Newlands Manor, Lymington.	4	.26	.17	.70	0.46
	West Mark, near Petersfield.	5	.16	.145	.84	.29
Oxford[c]	Wick. Farm:					
	Headington, I..........	2	.03	.049	.45	Trace.
	Headington, II.........	3	.19	.12	5.49	Trace.
Berkshire[d]	Sutton's seed trial grounds, Reading.	1	.17	.37	.80	.10
					CaCO$_3$	
Wiltshire[e]	Christchurch Allotment Station, Warminster.	....	.38	.34	4.17	.27
	Boreham road, Warminster.	....	.369	.258	.195	.21
			.31	.30	.165	.29
	Horningsham............	....	.366	.254	.125	.18
	Heytesbury.............	....	.42	.45	55.36	.13
	Codford allotment soil.....	....	.179	.466	12.21	....
	Chitterne allotment soils...	....	.246	.908	47.50	....
	Imber allotment...........	1	.154	.370	42.35	....
		2	.259	.402	49.97	....
	Corsley plot..............	....	.459	.134	.60	....
	Clay soil, Warminster......	....	.184	.255	25.55	....
	York warp soil............	....	.308	.223	4.17	....
Kent[f]	London clay:					
	Whitstable	....	1.13	.119	.35	2.02
	Sheppey...............	....	1.44	.111	.224	1.24
	Chalk soils:					
	Wye..................	....	.345	.143	7.91	.193
	Minster, Thanet........	....	.478	.101	1.96	.58
			.459	.094	3.70	.64
	Sutton-by-Dover.......	....	.432	.192	18.1	.69
	Meopham..............	....	.59	.126	12.2	.62
	Wye Court.............	....	....	.244	31.4	....
			....	.151	14.84	....
	Wye S. E. A. C........	....	....	.194	33.4	....
	Olantigh..............	....	....	.180	47.7	....
	Wye..................	....	....	.177	28.6	....
	Charing...............	....	.623	.217	30.9	....
	East Lenham..........	....	.64	.109	14.2	....
	Charing...............	....	.479	.132	.44	....
			1.07	.136	.99	....
	Gault soils:					
	Brook................	....	.899	.133	2.52	.040
			.901	.253	.019	.072
	Westwell.............	....	.739	.084	.061	....
			....	.048	2.42	....
	Charing...............	....	....	.038	.20	....
	East Lenham..........	....	.837	.12	13.2	....
	Brook................	....	.915	.16	.022	....
			1.01	.131	1.76	....
	East Lenham..........	....	.64	.199	10.6	....
	Hothfield.............	....	.515	.132	.85	....
Surrey[f]	London clay:					
	Wanborough Station...	....	.329	.065	.065	.35
	Ashtead Common......	....	.76	.093	.002	1.12
	Wyke................	....	.36	.061	.24	....
	Flexford.............	....	.478	.066	2.4	....
	Stoughton............	....	....	.053	.057	....
	Wanborough..........	....	.493	.078	.03	....
	Raynes Park.........	....	.67	.097	.073	....
	Horsley..............	....	.45	.116	.19	....
	Chalk soils:					
	Seale................	....	.236	.18	56.9	.40
	Fetcham.............	....	.298	.193	39.0	2.81
	Puttenham...........	....	....	.166	53.6	....
	Wanborough..........	....	....	.163	61.4	....
	Sutton..............	....	.265	.138	6.98	....

[a] Tenth Annual Report on Experiments in Cumberland, Durham, and Northumberland.

[b] Gilchrist and Foulkes, Suppl. I, Jour. Extension College, Reading, 1896.

[c] Gilchrist and Foulkes, Suppl. I, Jour. Extension College, Reading, 1896.

[d] Gilchrist and Foulkes, Suppl. I, Jour. Extension College, Reading, 1896.

[e] Report on Experiments, Wilts County Council Technical Education Committee, 1892, 1893, 1895.

[f] Hall and Plymen. South-Eastern Agricultural College, Wye, First Report on Chemical and Physical Study of the Soils of Kent and Surrey, 1902.

Chemical composition of the soils of Great Britain and Ireland—Continued.

ENGLAND—Continued.

County.	Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Surrey	Gault soils, Alder Holt	....	0.968	0.092	0.040	0.009
			....	.151	.025	....
			....	.074	.039	....
			.394	.0895	.024	....
	WALES.[a]					
					CaO.	
	Garden soil	....	0.142	0.306	1.40	0.671
	SCOTLAND.[b]					
	Cleghorn, near Lanark:				$CaCO_3$.	
	Plot 1	....	0.187	0.104	0.44	....
	Plot 2	....	.116	.126	.32	....
					CaO.	
	Drumfork, Helensburgh	....	.237	.45	0.168	....
	Easterboard, Croy	....	.213	.128	.403	....
	Birgidale Knock, Rothesay	....	.928	.244	.638	....
	Tarves	....	.539	.481	.594	....
	Wester Fintray, Kintore	....	.244	.283	.593	....
	Fedderate, Maud	....	.247	.367	.568	....
	Tulloch, Lumphanan	....	.279	.113	.826	....
	Fasque, Fettercairn	....	.463	.214	.759	....
	IRELAND.[c]					
Cork	Limestone soils, Shanagany	....	0.464	0.148	3.938	....
	Old red sandstone, Killeagh	....	.547	.156	.201	....
Wexford	Silurian clay slate soils:					
	Bally-Carney	....	.384	.156	.268	....
	Clonroche	....	.720	.167	.301	....
Tipperary	Limestone soils:					
	Rockford	....	.846	.16	1.568	....
	St. Kieran's	....	.943	.13	1.266	....

[a] Annual Report Field Experiments, University College of Wales, Aberystwyth, 1899.

[b] Reports on Experiments, 1893, Glasgow and West of Scotland Technical College.
Reports on Experiments, 1895, Glasgow and West of Scotland Technical College.
Reports on Experiments, 1903 and 1904, Aberdeen and North of Scotland College of Agriculture.

[c] H. C. Sheringham. Irish Agricultural Organisation Society. 1st Annual Report of Field Experiments in Counties of Wexford, Cork, Tipperary, Mayo, Meath, King's County and Queen's County, 1899.

England.—Two hundred and sixty-nine samples were reported upon from England, the range in composition being for potash 0.03 to 1.58 per cent, phosphoric acid 0.034 to 1.24 per cent, lime 0.002 to 61.4 per cent, and magnesia 0.009 to 2.81 per cent.

Wales.—Only one sample has been reported upon from Wales having 0.142 per cent potash, 0.306 per cent phosphoric acid, 1.4 per cent lime, and 0.671 per cent magnesia.

Scotland.—Ten samples were reported upon from Scotland the range in composition being for potash 0.116 to 0.928 per cent, phosphoric acid 0.104 to 0.481 per cent, and lime 0.168 to 0.826 per cent.

Ireland.—Six samples were reported upon from Ireland, the range in composition being for potash 0.384 to 0.943 per cent, phosphoric acid 0.13 to 0.167 per cent, and lime 0.201 to 3.938 per cent.

Chemical composition of the soils of France.

AISNE.[a]

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime ($CaCO_3$).	Magnesium (MgO).
LAON.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Semilly	1	0.36	0.09	11.22	0.007
	4	.60	.11	5.07	.003
	6	.22	.07	.52	.004
Chambry	1	.29	.18	5.44	.004
	3	.21	.09	7.45	.01
	5	.27	.13	34.12	.01
	7	.28	.14	15.55	.004
	8	.08	.03	.92	.005
	10	.28	.06	.86	.005
Bucy-les-Cerny	1	.44	.16	1.76	.01
	3	.41	.07	3.36	.005
	5	.44	.09	6.32	.01
Crépy-en-Laonnois	1	.28	.06	.96	.05
	3	.29	.08	2.83	.02
	7	.22	.07	34.53	.01
	9	.16	.06	.60	.01
	11	.24	.08	.32	.006
	14	.25	.10	2.40	.01
	16	.19	.12	7.64	.01
	17	.27	.10	58.00	.01
Vorges	1	.20	.24	5.56	.01
	3	.20	.08	1.04	.005
	5	.22	.08	.60	.01
	7	.33	.10	1.98	.004
	8	.06	.06	59.50	.01
	9	.48	.08	9.36	.01
Presles	1	.38	.06	3.71	.03
	3	.12	.04	3.52	.005
	5	.30	.05	.15	.005
Montbérault	1	.37	.08	64.75	.02
	3	.20	.06	2.43	.01
	5	.47	.10	1.10	.06
	8	.07	.04	.18	.005
	11	.42	.11	10.40	.16
	13	.32	.05	4.69	.005
	15	.29	.08	.71	.04
Chevregny	1	.16	.02	.64	.02
	3	.47	.07	2.24	.02
	5	.16	.08	.64	.01
	7	.28	.07	.96	.01
	8	.26	.03	29.20	.01
	9	.21	.07	7.80	.004
	11	.52	.03	.76	.01
	13	.70	.26	7.08	.02
	15	.71	.10	37.00	.005
Urcel	1	.10	.03	.09	.01
	3	.22	.09	4.64	.18
	6	.25	.05	.17	.003
	7	.30	.09	1.12	.015
	9	.12	.04	31.31	.005
Quincy-Basse	1	.10	.08	1.08	.005
	3	.26	.07	2.68	.05
	5	.16	.08	.88	.02
Landricourt	1	.12	.06	.08	.01
	3	.19	.06	.60	.005
	6	.30	.08	.48	.02
	8	.30	.08	.92	.01
	10	.39	.10	1.72	.02
Jumencourt	1	.18	.08	9.20	.006
	2	.57	.08	.76	.27
	4	.18	.08	39.70	.01
Folembray	1	.25	.03	1.60	.01
	3	.12	.04	.08	.02
	5	.22	.03	2.93	.08
	7	.15	.03	.32	.003
	8	.11	.04	1.70	.02
	10	.15	.05	.50	.01
Leuilly-sous. Coucy	1	.22	.09	1.76	.006
	3	.24	.10	2.00	.007
	4	.26	.06	.52	.005
	7	.23	.05	.37	.003
Crécy-au-Mont	1	.23	.12	4.94	.01
	3	.27	.07	.28	.01
	5	.29	.11	.68	.02
	7	.25	.08	.64	.39
	9	.19	.06	51.20	.01
	11	.47	.09	7.98	.01

[a] Bul. Sta. Agron. Dép. de l'Aisne, 1892, 1893, 1894.

Chemical composition of the soils of France—Continued.

AISNE—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime ($CaCO_3$).	Magnesium (MgO).
LAON—continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Crécy-au-Mout	13	0.50	0.07	0.72	0.02
	15	.15	.04	2.39	.01
Pont-Saint-Mard	1	.18	.06	.24	.006
	3	.25	.08	.52	.006
	5	.26	.08	32.30	.03
	7	.30	.03	.17	.006
	9	.26	.06	.84	.005
Vaudesson	3	.17	.06	.72	.02
	5	.21	.08	17.08	.01
	6	.38	.10	.18	.02
	8	.19	.06	.41	.01
	10	.33	.08	.18	.004
	12	.25	.05	1.00	.47
Couvrelles	1	.55	.13	2.12	.006
	5	.40	.06	.15	.006
	7	.27	.06	.40	.006
	9	.39	.03	3.23	.005
	11	.26	.04	.15	.02
	13	.38	.09	.79	.07
	15	.31	.09	.86	.06
Mercin	1	.20	.09	.72	.01
	3	.22	.11	.73	.01
	7	.28	.06	1.00	.01
	9	.23	.04	.36	.004
	11	.22	.04	3.14	.04
	13	.08	.13	.55	.01
Amifontaine	1	.24	.24	7.08	.004
	3	.23	.10	13.21	.005
	4	.13	.09	10.60	.007
	5	.39	.19	33.92	.006
	6	.15	.19	10.48	.005
	7	.45	.13	33.70	.006
	8	.18	.06	9.34	.01
	10	.29	.16	63.80	.007
	11	.26	.09	14.40	.007
Juvincourt	1	.23	.09	13.12	.005
	2	.14	.07	1.34	.01
	4	.28	.11	35.50	.12
Berry-au-Bac	1	.37	.16	49.20	.03
	2	.32	.21	25.00	.03
	4	.30	.12	23.60	.04
Gernicourt	1	.29	.10	4.82	.01
	2	.09	.02	.68	.005
	4	.32	.16	9.90	.006
	6	.27	.27	30.70	.06
	7	.17	.07	75.90	.01
Clermont-les-Fermes	1	.25	.10	.57	.02
	3	.37	.17	6.00	.01
	5	.20	.11	1.28	.003
	7	.30	.12	2.19	.003
	9	.31	.08	.98	.002
	11	.35	.10	.45	.003
	13	.25	.08	.36	.04
	15	.21	.08	.16	.005
	17	.43	.10	3.80	.004
Missy-les-Pierrepont	1	.19	.06	.29	.006
	3	.27	.15	2.24	.008
	4	.40	.07	2.66	.07
	6	.29	.06	.38	.03
	8	.28	.09	.70	.02
Grandlup	1	.35	.13	30.94	.01
	2	.21	.08	22.20	.01
	3	.24	.06	.28	.01
	5	.40	.14	1.63	.01
	7	.38	.14	3.08	.01
	8	.15	.09	1.63	.01
Frières-Faillouel	1	.19	.08	1.70	.006
	3	.29	.09	5.16	.01
	5	.30	.07	.38	.10
	9	.35	.09	5.46	.005
	10	.33	.07	2.32	.01
Liez	1	.25	.11	3.06	.005
	4	.32	.07	5.24	.01
	6	.22	.08	3.18	.004
	8	.27	.12	39.50	.01
	10	.20	.11	1.05	.005
	12	.18	.20	.36	.01
	14	.24	.08	1.33	.01

Chemical composition of the soils of France—**Continued.**

AISNE—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime ($CaCO_3$).	Magnesium (MgO).
LAON—continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Charmes	1	0.47	0.11	0.58	0.003
	3	.25	.07	2.62	.02
	5	.58	.13	5.28	.004
	7	.15	.09	1.56	.004
	9	.27	.09	1.60	.01
	12	.85	.12	7.04	.01
Rogécourt	1	.28	.10	3.08	.05
	3	.13	.08	2.03	.07
	5	.24	.08	3.14	.01
	8	.28	.09	1.13	.006
	9	.23	.04	3.68	.02
Fressancourt	1	.28	.08	.52	.02
	3	.29	.08	1.96	.05
	5	.26	.10	2.32	.008
	7	.28	.10	5.84	.005
Faucouzy	1	.31	.10	4.50	.04
	4	.37	.15	3.40	.05
	5	.32	.20	65.50	.003
	6	.34	.09	.72	.04
	8	.60	.18	28.80	.004
	10	.22	.11	2.40	.06
	12	.61	7.14	19.70	.02
	14	.35	6.87	62.00	.01
Chevresis-Monceau	1	.28	.10	5.10	.01
	3	.22	.10	33.88	.005
	5	.08	.05	35.08	.01
	7	.25	.10	15.65	.004
	9	.05	.10	48.30	.004
Grugies	1	.34	.08	.25	.01
	4	.35	.14	4.76	.01
	6	.45	.06	8.22	.005
	8	.27	.04	41.44	.005
	9	.24	.08	.46	.006
Crézancy	1	.20	.06	34.20	.02
	5	.29	.03	.54	.01
	7	.47	.10	8.26	.02
	11	.33	.09	10.20	.01
Épieds	1	.21	.07	1.15	.006
	3	.26	.06	.28	.01
	6	.27	.06	.78	.02
	9	.48	.07	16.98	.01
	11	.21	.06	.68	.02
	13	.19	.05	1.50	.02
Torcy	1	.19	.05	.68	.006
	3	.09	.04	1.28	.006
	5	.18	.06	8.91	.04
	7	.26	.08	3.30	.03
	9	.20	.05	.61	.01
	11	.35	.05	.98	.02
Pouilly-sur-Serre	1	.23	.15	2.19	.004
	3	.35	.04	.45	.003
	5	.25	.04	5.24	.005
	7	.32	.04	.34	.005
	9	.30	.23	8.00	.004
	10	.30	.06	33.93	.005
	13	.65	.05	3.25	.003
Nouvion-et-Catillon	1	.33	.03	.80	.005
	3	.39	.10	.50	.003
	5	.43	.05	1.70	.01
	6	.42	.11	1.42	.006
	8	.30	.08	.48	.006
	10	.30	.09	.70	.005
	12	.37	.07	1.28	.01
	13	.35	.07	.48	.01
	15	.24	.12	53.20	.006
Mesbrecourt-Richecourt	1	.35	.11	4.20	.006
	3	.37	.14	.38	.005
	5	.58	.08	.39	.01
	7	.32	.13	1.18	.01
	9	.26	.11	49.00	.01
	10	.46	.05	1.30	.006
	12	.44	.11	1.24	.01
	14	.51	.10	.39	.01
	16	.27	.12	1.16	.006
La Ferté-Chevresis	1	.34	.08	2.58	.01
	3	.46	.11	1.16	.01
	5	.38	.13	.74	.01

Chemical composition of the soils of France—Continued.

AISNE—Continued.

Description and locality.	Original sample No.	Potash (K$_2$O).	Phosphoric acid (P$_2$O$_5$).	Lime (CaCO$_3$).	Magnesium (MgO).
LAON—continued.					
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
La Ferté-Chevresis	7	0.30	0.11	28.44	0.004
	8	.37	.19	45.16	.01
	9	.31	.12	1.95	.005
	11	.69	.16	.67	.006
	13	.32	.11	9.98	.01
Valécourt	1	.33	.20	56.45	.005
	2	.57	.06	2.60	.006
	5	.39	.07	3.94	.01
	7	.37	.10	.66	.01
	10	.32	.08	36.80	.01
	11	.37	.09	1.24	.01
Pargny-les-Bois	1	.32	.04	.30	.01
	3	.13	.13	62.00	.01
	6	.42	.10	1.06	.01
Bois-les-Pargny	1	.33	.05	.28	.05
	3	.48	.08	.84	.004
	5	.21	.09	.38	.01
	7	.34	.07	.64	.01
Erlon	1	.14	.08	1.36	.01
	3	.29	.08	.52	.01
	5	.28	.09	.46	.002
	7	.30	.07	.37	.01
	9	.24	.05	.70	.02
	11	.15	.14	62.45	.04
Marcy	1	.20	.04	.32	.003
	3	.30	.15	37.00	.003
	5	.36	.12	.60	.10
	7	.27	.08	.41	.006
Voyenne	1	.23	.08	.68	.01
	3	.37	.13	.18	.01
	5	.31	.12	7.88	.01
	7	.27	.14	15.53	.01
	9	.28	.18	7.96	.01
Marle	1	.42	.16	.85	.006
	3	.31	.07	1.00	.01
	5	.41	.09	.70	.02
	7	.23	.07	.80	.02
	9	.47	.14	.80	.01
Houry	1	.42	.09	1.18	.01
	3	.50	.18	1.44	.01
	6	.27	.10	1.65	.02
	8	.48	.13	2.96	.01
	10	.35	.09	4.78	.01
Prisces	1	.61	.15	.76	.006
	3	.30	.16	1.47	.005
	5	.53	.23	.64	.007
	7	.34	.13	1.30	.006
	9	1.30	.80	.70	.006
Gronard	1	.33	.08	1.04	.03
	4	.26	.07	.56	.003
	6	.28	.03	1.84	.005
Agnicourt-et-Séchelles	1	.28	.11	3.00	.02
	3	.28	.26	8.08	.01
	5	.30	.10	1.18	.01
	7	.26	.18	2.55	.01
	9	.25	.25	53.50	.02
	10	.51	.15	.68	.01
	12	.30	.10	.32	.01
	14	.21	.17	87.00	.01
Montloué	1	.23	.07	.32	.01
	3	.28	.09	.68	.01
	5	.45	.08	.78	.01
	7	.21	.15	56.00	.02
	9	.35	.17	1.68	.04
Noircourt	1	.43	.06	5.88	.01
	3	.50	.08	.36	.006
	5	.29	.06	3.55	.02
	7	.41	.11	13.50	.003
	11	.15	.16	38.00	.006
	12	.40	.08	.98	.01
	14	.14	.10	1.97	.02
	16	.43	.06	1.36	.03
	18	.35	.05	.48	.01
Goudelancourt	1	.39	.18	26.50	.004
	3	.23	.07	.50	.005
	5	.41	.10	.72	.01

Chemical composition of the soils of France—**Continued.**

AISNE—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime ($CaCO_3$).	Magnesium (MgO).
LOAN—continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Ebouleau	1	0.52	0.08	0.25	0.004
	3	.39	.07	.40	.004
	5	.25	.09	.42	.007
	7	.28	.05	42.00	.007
Bucy-les-Pierrepont	1	.16	.06	.42	.003
	3	.24	.08	29.50	.004
	5	.20	.07	.52	.02
	7	.44	.08	.42	.01
	9	.39	.07	.34	.003
	11	.40	.06	.44	.01
	13	.27	.02	.12	.004
	15	.37	.08	.72	.01
Boncourt	1	.25	.09	.28	.12
	3	.29	.07	.26	.03
	5	.28	.10	.48	.01
	7	.28	.08	.80	.11
Lappion	1	.30	.11	47.00	.02
	3	.14	.04	.22	.01
	5	.23	.04	.12	.02
	6	.26	.05	.28	.02
	8	.29	.07	.24	.02
	10	.28	.15	94.70	.19
	13	.37	.04	.64	.03
La Selve	1	.32	.04	1.84	.02
	2	.14	.08	48.00	.007
	3	.26	.07	.78	.02
Sissonne	1	.24	.21	43.00	.005
	3	.33	.07	9.20	.004
	4	.24	.09	.80	.004
	5	.24	.13	23.22	.003
	6	.28	.15	15.64	.007
	7	.30	.50	16.19	.003
	8	.49	.32	10.71	.005
	9	.14	.06	.52	.004
	10	.12	.04	.24	.004
Machecourt	1	.29	.12	49.00	.009
	3	.35	.03	.80	.006
	5	.39	.11	1.40	.002
	7	.44	.06	1.96	.01
Chivres	1	.47	.17	20.00	.004
	3	.24	.14	46.60	.003
	4	.23	.05	.24	.01
	6	.41	.19	5.64	.23
Liesse	1	.27	.04	1.63	.004
Gizy	1	.20	.03	.52	.009
	3	.47	.04	.38	.007
	5	.30	.05	.20	.01
	7	.27	.09	.68	.02
Samoussy	1	.37	.06	.24	.006
	4	.27	.14	39.75	.01
	6	.24	.10	2.60	.01
	8	.23	.17	26.00	.02
Monceau-le-Waast	1	.25	.08	2.97	.01
	3	.19	.14	3.25	.03
Athies	1	.38	.12	.52	.01
	2	.40	.06	.28	.01
	4	.23	.09	1.00	.004
	6	.22	.07	.80	.007
	8	.29	.06	14.00	.006
	9	.27	.03	.64	.004
Eppes	1	.31	.09	86.00	.006
	2	.30	.06	8.00	.006
Coucy-les-Eppes	1	.16	.04	.30	.005
	3	.45	.06	.42	.004
	5	.19	.07	.36	.01
	6	.21	.03	.30	.001
	8	.47	.17	7.30	.01
	9	.29	.09	35.50	.003
	10	.25	.09	2 10	.003
Festieux	1	.16	.03	.16	.004
	3	.25	.07	10.50	.005
	4	.29	.13	25.44	.006
	5	.50	.06	1.50	.007
Veslud	1	.19	.04	.24	.003
	3	.18	.03	.04	.03
	4	.33	.05	.88	.004
	6	.35	.13	20.00	.01

Chemical composition of the soils of France—Continued.

AISNE—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime ($CaCO_3$).	Magnesium (MgO).
LOAN—continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Parfondru	1	0.32	0.10	0.16	0.007
	2	.52	.15	2.88	.01
	5	.26	.05	5.40	.02
Bruyères	1	.14	.05	.24	.02
Arrancy	1	.32	.07	1.00	.008
	3	.27	.03	.84	.007
	5	.21	.05	10.88	.006
Ployart	1	.24	.11	.63	.007
	3	.44	.06	3.37	.03
	5	.18	.10	2.40	.01
Vaureseine	1	.37	.09	20.00	.007
	3	.33	.06	10.00	.02
	5	.24	.12	.40	.006
Montchalons	1	.40	.16	.60	.008
	3	.32	.10	3.40	.005
	5	.32	.04	.20	.005
Chérêt	1	.36	.07	47.00	.02
	2	.36	.07	19.00	.02
Orgeval	1	.25	.06	1.40	.007
	4	.27	.14	.84	.004
Bièvres	1	.26	.10	.44	.03
	3	.36	.17	20.00	.01
	4	.28	.10	11.00	.006
Martigny	1	.36	.07	1.10	.007
	3	.33	.07	13.06	.05
	4	.39	.12	13.18	.31
	5	.40	.07	.46	.08
Monampteuil	1	.20	.07	.99	.002
	3	.27	.05	.19	.005
	5	.20	.07	.23	.004
	7	.19	.07	.24	.005
	9	.34	.07	.45	.005
Braisne	1	.23	.67	.50	.03
	3	.28	.06	.48	.02
	5	.20	.05	.84	.02
	7	.17	.12	7.00	.01
Brenelle	1	.35	.04	.48	.01
Courcelles	1	.34	.05	.78	.01
	3	.47	.08	1.66	.03
	5	.24	.08	1.26	.03
	7	.28	.05	65.00	.01
	8	.16	.04	27.00	.01
	10	.20	.07	.44	.01
Limé	1	.32	.05	.74	.02
	3	.23	.05	.26	.01
	5	.31	.07	.42	.01
	7	.64	.07	.70	.01
	9	.32	.91	29.00	.01
Quincy-sous-Le-Mont et Bruyères	2	.26	.05	.30	.02
	4	.27	.06	.41	.005
	6	.24	.09	.56	.01
	8	.22	.05	.58	.01
Laffaux	1	.24	.05	1.09	.008
	3	.37	.07	1.90	.008
	5	.22	.06	.52	.007
Neuville-sur-Margival	1	.42	.07	.48	.01
	3	.29	.06	.30	.005
Terny-Sorny	1	.36	.06	1.42	.006
	3	.39	.12	21.20	.006
	5	.38	.06	1.22	.003
	7	.26	.06	.42	.004
	9	.30	.07	.72	.02
Margival	1	.28	.06	3.68	.01
	3	.48	.08	2.02	.01
	5	.28	.08	.82	.005
	7	.28	.05	81.00	.005
	9	.26	.06	3.68	.008
Vuillery et Braye-sous-Clamecy	1	.28	.07	.34	.003
Villemontoire	1	.24	.13	5.10	.02
	3	.29	.09	.72	.01
	5	.16	.07	18.20	.03
	7	.20	.09	.82	.03
	9	.16	.08	.60	.007
Buzancy	1	.27	.04	.98	.01
	3	.33	.06	1.70	.01
	5	.31	.06	.40	.006
	8	.31	.07	3.41	.03

Chemical composition of the soils of France—Continued.

AISNE—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime $CaCO_3$).	Magnesium (MgO .
LAON—continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Aconin	1	0.33	0.08	9.70	0.01
	3	.30	.09	1.10	.01
	4	.32	.06	.86	.02
	6	.37	.16	.40	.006
Cutry	1	.3	.05	.10	.005
	3	.38	.07	.24	.01
	5	.66	.07	1.88	.01
	7	.38	.06	.48	.004
Cœuvres-et-Valsery	1	.38	.08	.20	.01
	3	.24	.06	.24	.006
	5	.26	.07	54.00	.01
	6	.34	.12	2.24	.008
	7	.37	.08	.36	.01
Saint-Pierre-Aigle	1	.29	.03	.48	.007
	3	.25	.07	.24	.01
Laversine	1	.33	.02	.28	.005
	3	.31	.08	.28	.01
Dommiers	1	.31	.06	.20	.01
	3	.37	.10	.36	.05
Berny-Rivière	1	.8	.12	41.90	.003
	2	.80	.14	17.00	.003
Nouvron	1	.57	.08	.73	.01
	3	.64	.09	.65	.01
	5	.32	.06	.45	.003
	7	.42	.06	5.09	.02
	8	.14	.01	86.70	.004
Morsain	1	.30	.05	2.16	.007
	2	.18	.07	.70	.005
	3	.22	.06	2.23	.005
	5	.20	.05	5.44	.01
Vézaponin	2	.30	.05	3.04	.01
	4	.50	.03	.50	.01
	6	.44	.05	.30	.01
Selens	1	.29	.28	1.48	.01
	4	.12	.06	44.00	.01
	5	.39	.06	3.00	.03
	8	.35	.08	.61	.01
	10	.26	.04	1.18	.03
Saint-Aubin	1	.26	.06	1.08	.05
	3	.15	.05	2.80	.06
Trosly-Loire	1	.24	.06	2.27	.04
	3	.16	.06	.68	.05
	4	.19	.08	1.52	.06
	5	.17	.07	.82	.06
	7	.22	.03	9.96	.06
	8	.17	.09	2.08	.05
	9	.22	.07	.78	.03
Villequier-Aumont	1	.32	.05	.68	.01
	4	.57	.22	.38	.004
	6	.26	.08	.38	.008
	8	.26	.05	.82	.01
	10	.28	.05	.38	.01
Landouzy-la-Cour	2	.27	.11	2.30	.01
	4	.32	.06	.64	.01
	6	.35	.10	.38	.01
	10	.23	.09	.60	.01
	12	.34	.08	.20	.007
	14	.39	.08	1.00	.006
Vervins	1	.27	.11	.32	.01
	3	.24	.10	.20	.007
	5	.36	.10	1.28	.01
Fontaine-les-Vervins	1	.28	.11	.60	.008
	3	.39	.10	93.00	.007
	4	.33	.10	.68	.009
	6	.32	.07	2.20	.006
	8	.40	.10	1.84	.007
Laigny	1	.29	.04	.44	.001
	3	.30	.10	.80	.006
	6	.30	.11	9.44	.01
Haution	1	.31	.08	1.24	.006
	3	.26	.09	.32	.007
Voulpaix	1	.31	.09	.56	.003
	2	.66	.07	.36	.007
	3	.24	.08	1.24	.01
	5	.28	.09	.88	.006

Chemical composition of the soils of France—Continued.

AISNE—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime ($CaCO_3$).	Magnesium (MgO).
LAON—continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Marfontaine	1	0.31	0.17	1.96	0.01
	2	.24	.06	.36	.01
	4	.28	.09	.52	.004
Rougeries	1	.33	.09	.92	.006
Presles	1	.25	.05	.35	.01
Nouvion	1	.47	.10	1.68	.006
	4	.30	.05	.15	.005
Laval	3	.27	.10	.56	.006
	6	.12	.06	.60	.02
Monthenault	1	.54	.07	.52	.005
	3	.46	.07	.16	.005
	5	.40	.04	.72	.004
	7	.40	.06	.06	.004
	8	.35	.04	1.64	.005
Chamouille	1	.32	.10	2.56	.05
	2	.38	.08	6.60	.006
Courtecon	1	.27	.06	.36	.006
	3	.26	.06	.70	.02
	5	.26	.06	.48	.003
	7	.37	.17	.96	.007
	10	.33	.08	11.30	.03
Pancy	1	.24	.02	.20	.007
	3	.52	.09	.52	.01
Colligis	1	.52	.07	.84	.01
	3	.58	.05	9.96	.007
Crandelain	1	.28	.05	.24	.007
	4	.29	.07	.22	.01
	6	.33	.05	.18	.005
Trucy	1	.36	.07	.28	.003
	3	.33	.03	.20	.004
Lierval	1	.32	.06	19.86	.22
	2	.56	.12	8.52	.01
Lesdins	1	.34	.14	.44	.01
	3	.30	.16	56.40	.004
	5	.39	.08	2.80	.02
	7	.38	.13	1.44	.01
Levergies	1	.27	.10	18.04	.02
	4	.27	.07	2.04	.02
	6	.36	.09	.92	.01
	8	.37	.10	.54	.01
Gouy	1	.39	.07	3.70	.01
	3	.59	.14	.76	.005
	5	.40	.12	.76	.01
	7	.17	.12	42.40	.01
	8	.51	.12	1.08	.006
	10	.50	.10	.60	.01
	12	.51	.09	1.76	.004
	14	.44	.09	11.92	.01
	16	.38	.10	.64	.01
Prouvais	1	.22	.08	.68	.007
	3	.29	.06	2.80	.02
	6	.40	.22	32.70	.01
	7	.21	.24	34.00	.01
	9	.46	.30	52.00	.02
	10	.22	.15	7.44	.01
Molinchart	1	.36	.09	3.40	.01
	3	.27	.04	.32	.005
Clacy	5	.38	.09	44.50	.01
Merlieux	1	.30	.11	6.40	.02
	2	.32	.23	2.06	.03
	3	.38	.06	.16	.003
	5	.32	.04	.16	.003
Montbavin et Montarsène	1	.37	.07	.62	.01
	3	.26	.05	.76	.01
	5	.19	.04	.40	.01
	7	.23	.04	.12	.01
	8	.28	.05	.22	.01
	9	.20	.08	27.00	.02
Barisis	1	.22	.06	.64	.007
	3	.38	.08	1.00	.004
	6	.23	.06	22.00	.005
	7	.29	.05	1.08	.003
Mont-Saint-Martin	1	.42	.09	6.70	.02
	3	.39	.10	1.04	.007
	5	.36	.09	15.60	.01
	8	.45	.06	.48	.01

Chemical composition of the soils of France—Continued.

AISNE—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime ($CaCO_3$).	Magnesium (MgO).
LAON—continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Nesles	1	0.23	0.06	0.48	0.02
	3	.38	.06	.28	.004
	5	.29	.06	.20	.005
	7	.26	.05	.60	.003
	9	.28	.10	.80	.01
Nogentel	3	.24	.06	32.00	.02
	4	.40	.23	5.80	.01
Étampes	1	.72	.09	1.36	.04
	2	.24	.12	7.50	.005
Chierry	1	.29	.15	15.92	.03
	3	.40	.20	20.00	.01
Fossoy	1	.77	.08	17.46	.03
	3	1.17	.12	13.74	.006
	5	.33	.06	14.96	.02
Seraucourt-le-Grand	1	.28	.14	3.53	.02
	3	.29	.06	.10	.02
	5	.50	.09	1.08	.01
	7	.28	.21	3.24	.007
Happencourt	1	.44	.15	3.23	.008
	3	.42	.22	31.00	.02
	5	.38	.10	8.64	.01
Artemps	1	.47	.13	2.98	.01
	3	.30	.10	1.56	.01
Clastres	1	.32	.05	.60	.006
Guise	1	.29	.08	.20	.02
	4	.64	.11	2.64	.03
	6	.40	.09	.70	.005
	8	.39	.03	.24	.003
Lesquielles-Saint-Germain	1	.27	.56	45.00	.01
	2	.46	.07	.72	.01
	4	.36	.12	3.04	.01
	6	.31	.10	.60	.008
Couvron	1	.31	.16	4.06	.04
	3	.34	.12	5.88	.03
	4	.17	.18	58.00	.02
	5	.21	.07	.20	.04
Barenton-Cel	1	.51	.10	2.62	.01
	3	.35	.09	8.70	.02
	4	.39	.09	1.62	.007
	6	.14	.19	72.00	.006
	8	.51	.08	.60	.003
	10	.41	.07	14.00	.009
Chalandry	1	.49	.09	1.80	.004
	3	.32	.12	2.10	.01
Cessiéres	1	.28	.12	.56	.001
	3	.33	.06	.36	.002
	5	.45	.05	.52	.002
	7	.34	.07	.36	.002
Guivry	2	.27	.07	.40	.003
	4	.24	.08	.48	.004
	8	.33	.09	.72	.004
Berlancourt	1	.38	.08	1.20	.02
	3	.43	.09	2.20	.05
	5	.27	.09	5.50	.01
	7	.23	.11	16.00	.006
	8	.36	.09	2.68	.02
Neuville-Saint-Amand	1	.41	.08	.20	.005
	3	.49	.12	2.00	.009
	5	.43	.03	2.16	.005
	7	.45	.16	47.00	.007
	8	.33	.07	3.02	.006
	10	.35	.07	1.40	.006
	12	.40	.09	1.60	.006
	15	.53	.18	1.00	.005
Remaucourt	1	.38	.16	3.36	.01
	3	.47	.13	1.62	.01
	6	.37	.12	2.52	.01
	9	.34	.22	39.50	.01
Vauxresis	1	.34	.07	.64	.002
Cuisy-on-Almont	1	.41	.09	.24	.004
	3	.31	.07	1.08	.002
Vieil Arcy	1	.36	.07	1.40	.003
	3	.14	.07	.40	.002
	5	.25	.07	16.00	.002
	7	.14	.10	3.16	.003
	10	.47	.25	13.60	.002

Chemical composition of the soils of France—Continued.

AISNE—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime ($CaCO_3$).	Magnesium (MgO).
LAON—continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Dhuizel	1	0.39	0.07	0.60	0.004
	8	.25	.07	.76	.003
Longpont	1	.65	.16	1.00	.002
	2	.30	.07	.92	.004
	4	.35	.11	1.10	.005
	6	.43	.06	1.00	.004
	9	.34	.09	16.80	.002
PAS-DE-CALAIS.[a]					
Erquières	1	0.268	0.119	0.405	....
	2	.137	.092	2.411	....
	3	.267	.098	1.836	....
	4	.267	.108	3.875	....
	5	.298	.211	15.565	....
	6	.219	.172	57.344	....
Guigny	1	.32	.143	1.652	....
	2	.35	.086	1.932	....
	3	.30	.104	1.897	....
	4	.289	.159	8.112	....
	5	.317	.121	35.971	....
Berthonval	1	.26	.10	1.17	....
	2	.33	.14	1.51	....
	3	.30	.115	.20	....
	4	.29	.22	23.39	....
	5	.34	.094	.925	....
Louez	1	.316	.116	.70	....
	2	.298	.118	1.20	....
	3	.388	.158	4.215	....
	4	.333	.19	4.265	....
	5	.319	.26	23.00	....
	6	.328	.252	23.00	....
Valhuon	1	.376	.096	1.12	....
	2	.314	.094	.716	....
	3	.245	.092	1.36	....
	4	.219	.094	1.05	....
	5	.266	.084	1.19	....
Saint-Martin	1	.121	.108	.135	....
	2	.176	.156	1.085	....
	3	.154	.15	.625	....
	4	.176	.156	2.70	....
	5	.169	.146	.475	....
	6	.185	.156	1.35	....
Longunesse	1	.191	.159	.533	....
	2	.198	.133	4.906	....
	3	.249	.121	1.183	....
	4	.248	.145	2.786	....
	5	.289	.153	1.848	....
	6	.30	.086	.648	....
	7	.198	.142	1.041	....
	8	.174	.098	1.041	....
Marck	1	.33	.116	18.011	....
	2	.256	.063	14.016	....
	3	.347	.129	25.145	....
	4	.25	.092	22.086	....
	5	.043	.031	.101	....
	6	.25	.116	14.974	....
Offekerque	1	.384	.104	16.412	....
	2	.29	.101	14.101	....
	3	.22	.092	13.834	....
	4	.291	.105	15.806	....
Guines	1	.235	.153	.96	....
	2	.282	.167	7.699	....
	3	.248	.254	21.334	....
	4	.324	.224	13.014	....
Faubourg Ronville	1	.26	.704	38.75	....
	2	.223	.704	34.427	....
	3	.257	.554	19.739	....
	4	.295	.40	4.572	....
	5	.258	.194	1.625	....
	6	.266	.642	9.939	....
Souastre	1	.268	.092	1.84	....
	2	.241	.091	1.47	....
	3	.277	.11	.518	....

[a] Pagnoul. Terres Arables de Pas-de-Calais, 1894. Bul. Sta. Agron. Pas-de-Calais, 1887-1895.

Chemical composition of the soils of France—Continued.

PAS-DE-CALAIS—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime ($CaCO_3$).	Magnesium (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Souastre	4	0.267	0.075	1.504	....
	5	.239	.09	2.053	....
	6	.29	.08	2.21	....
	7	.249	.092	2.596	....
Pas	1	.262	.08	1.02	....
	2	.208	.134	3.866	....
	3	.311	.081	3.112	....
	4	.345	.08	.97	....
	5	.245	1.28	.923	....
	6	.256	.056	.031	....
	7	.177	.25	62.448	....
	8	.199	.104	1.62	....
	9	.31	.10	2.72	....
Serres	1	.278	.123	.961	....
	2	.122	.143	.468	....
	3	.30	.118	4.17	....
	4	.255	.106	.75	....
	5	.315	.114	1.62	....
	6	.263	.107	2.02	....
	7	.268	.11	1.11	....
Fresnes-lez-Montauban	1	.277	.162	33.272	....
	2	.36	.11	1.972	....
	3	.257	.085	1.901	....
	4	.323	.11	1.633	....
	5	.292	.231	42.112	....
Adinfer	1	.367	.114	1.14	....
	2	.337	.10	.861	....
	3	.307	.094	.526	....
	4	.262	.093	.774	....
	5	.286	.103	2.462	....
	6	.30	.106	1.208	....
	7	.288	.084	.125	....
	8	.253	.071	.077	....
Hénin-sur-Cojeul	1	.289	.186	14.40	....
	2	.228	.115	2.53	....
	3	.262	.123	2.30	....
	4	.313	.096	1.15	....
	5	.268	.163	10.42	....
	6	.313	.094	.93	....
Achicourt	1	.277	.571	7.173	....
	2	.263	.292	7.698	....
	3	.278	.16	1.901	....
	4	.329	.149	1.288	....
	5	.295	.159	2.263	....
	6	.257	.57	35.968	....
	7	.278	.584	32.988	....
	8	.355	.14	2.68	....
	9	.317	.329	4.67	....
Croisilles	1	.334	.109	2.061	....
	2	.286	.108	.592	....
	3	.308	.114	.992	....
	4	.305	.103	1.511	....
	5	.265	.114	12.525	....
	6	.325	.125	1.003	....
	7	.26	.157	16.67	....
	8	.282	.093	.459	....
La Herlière	1	.275	.075	2.917	....
	2	.273	.066	3.00	....
	3	.276	.08	1.904	....
	4	.249	.099	4.857	....
	5	.276	.089	2.145	....
Moyenneville	1	.309	.102	.614	....
	2	.317	.091	.208	....
	3	.317	.107	.774	....
	4	.306	.099	.811	....
	5	.215	.103	.381	....
	6	.345	.133	.684	....
Ablainzevelle	1	.316	.102	.603	....
	2	.162	.114	.59	....
	3	.304	.092	.359	....
	4	.266	.072	.251	....
	5	.269	.071	1.53	....
	6	.292	.102	.429	....
	7	.224	.073	1.845	....
	8	.25	.071	.102	....
	9	.269	.085	2.652	....
	10	.255	.081	.28	....

Chemical composition of the soils of France—Continued.

PAS-DE-CALAIS—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime $CaCO_3$).	Magnesium (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Havrincourt	1	0.272	0.111	1.537	....
	2	.237	.097	.799	....
	3	.283	.137	3.646	....
	4	.319	.103	.605	....
	5	.237	.124	3.469	....
	6	.309	.128	1.652	....
	7	.275	.09	.62	....
	8	.337	.159	.87	....
	9	.35	.106	.848	....
	10	.341	.122	2.628	....
	11	.25	.103	1.578	....
	12	.206	.27	39.918	....
Hesdigneul	1	.248	.081	.573	....
	2	.276	.087	.57	....
	3	.257	.139	.877	....
	4	.337	.116	1.687	....
	5	.268	.067	.245	....
	6	.205	.074	1.171	....
	7	.264	.073	.051	....
	8	.266	.072	.243	....
	9	.182	.095	.255	....
	10	.322	.126	1.413	....
Metz-en-Couture	1	.272	.116	2.536	....
	2	.228	.111	.93	....
	3	.227	.133	1.734	....
	4	.239	.107	.568	....
	5	.323	.131	.753	....
	6	.233	.105	.711	....
	7	.289	.118	2.344	....
	8	.218	.15	.876	....
	9	.218	.098	1.996	....
	10	.243	.105	.537	....
	11	.22	.103	2.599	....
Fontaine-lez-Boulans	1	.308	.096	1.884	....
	2	.38	.314	11.117	....
	3	.365	.083	65.90	....
	4	.297	.073	3.899	....
	5	.503	.39	14.713	....
	6	.545	.422	30.198	....
Clairmarais	1	.253	.054	2.171	....
	2	.414	.088	.675	....
	3	.284	.07	1.514	....
	4	.26	.069	.902	....
	5	.36	.081	1.022	....
	6	.378	.26	33.837	....
	7	.31	.078	2.12	....
	8	.31	.142	16.783	....
	9	.53	.10	3.685	....
Wizernes	1	.249	.074	.253	....
	2	.379	.063	1.059	....
	3	.271	.06	1.33	....
Racquinghem	1	.385	.072	.00	....
	2	.31	.093	.671	....
	3	.28	.099	.774	....
	4	.266	.086	1.224	....
	5	.353	.114	1.237	....
	6	.282	.039	1.003	....
	7	.557	.045	.929	....
	8	.761	.038	.608	....
	9	.178	.00	.00	....
Houlle	1	.232	.085	2.204	....
	2	.245	.161	28.211	....
	3	.254	.147	29.757	....
	4	.161	.309	3.034	....
	5	.304	.105	5.803	....
Moulle	1	.217	.082	2.203	....
	2	.171	.088	1.463	....
	3	.279	.105	4.167	....
	4	.21	.111	2.648	....
	5	.178	.102	3.439	....
Zoteux	1	.201	.126	2.08	....
	2	.293	.117	.436	....
	3	.287	.223	6.007	....
	4	.395	.209	1.807	....
	5	.196	.104	.212	....
	6	.272	.193	4.813	....

Chemical composition of the soils of France—Continued.

PAS-DE-CALAIS—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime ($CaCO_3$).	Magnesium (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Mentque-Nortbécourt	1	0.144	0.162	61.819	....
	2	.292	.141	12.013	....
	3	.196	.141	6.114	....
	4	.297	.159	7.612	....
	5	.197	.151	39.253	....
	6	.266	.133	11.502	....
Isques	1	.404	.176	7.955	....
	2	.314	.139	1.005	....
	3	.199	.073	2.163	....
	4	.236	.092	.174	....
	5	.234	.09	.242	....
	6	.466	.257	9.746	....
Hubersent	1	.358	.248	8.238	....
	2	.147	.136	32.749	....
	3	.202	.093	3.213	....
	4	.272	.079	.328	....
	5	.211	.084	2.803	....
	6	.20	.071	.092	....
Bailleul-lez-Pernes	1	.357	.066	23.371	....
	2	.243	.079	.796	....
	3	.301	.083	1.466	....
	4	.214	.065	1.247	....
	5	.287	.121	.873	....
	6	.30	.175	6.479	....
Auchy-lez-Hesdin	1	.195	.124	3.594	....
	2	.224	.091	.332	....
	3	.27	.119	.694	....
Rang-du-Fliers	1	.23	.057	18.422	....
	2	.135	.086	2.065	....
	3	.225	.277	17.465	....
	4	.219	.061	21.053	....
	5	.208	.051	17.912	....
	6	.143	.083	14.489	....
Labourse	1	.40	.219	25.177	....
	2	.325	.225	23.305	....
	3	.281	.131	23.511	....
	4	.234	.087	1.00	....
	5	.257	.102	1.678	....
	6	.306	.219	23.619	....
	7	.342	.208	19.108	....
Feuchy	1	.329	.183	6.948	....
	2	.254	.086	.78	....
	3	.316	.092	1.124	....
	4	.165	.103	.55	....
	5	.317	.285	27.373	....
	6	.403	.189	7.627	....
Coupelle-Vielle	1	.232	.10	4.968	....
Boiry-Notre-Dame	1	.306	.092	.715	....
	2	.275	.092	.756	....
	3	.292	.088	.745	....
	4	.268	.088	.817	....
	5	.242	.093	1.069	....
	6	.277	.081	1.377	....
	7	.185	.043	.258	....
	8	.276	.098	.50	....
	9	.281	.077	.76	....
	10	.30	.086	.753	....
	11	.321	.185	18.21	....
	12	.297	.073	.64	....
	13	.28	.082	.372	....
	14	.251	.078	.616	....
Givenchy-en-Gohelle	1	.315	.136	1.224	....
	2	.366	.132	1.283	....
	3	.386	.155	3.864	....
	4	.282	.127	.88	....
	5	.367	.124	5.42	....
	6	.436	.178	5.891	....
Pénin	1	.306	.119	.769	....
	2	.261	.149	9.243	....
	3	.333	.149	3.681	....
	4	.203	.202	63.776	....
	5	.267	.139	1.119	....
	6	.331	.14	2.472	....
Baralle	1	.245	.093	2.246	....
	2	.224	.102	1.763	....
	3	.262	.272	14.719	....
	4	.289	.133	.741	....
	5	.269	.249	9.838	....
	6	.331	.164	3.219	....

Chemical composition of the soils of France—Continued.

PAS-DE-CALAIS—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime ($CaCO_3$).	Magnesium (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Rebergues	1	0.35	0.206	14.421	....
	2	.647	.126	1.495	....
	3	.27	.222	47.525	....
	4	.32	.373	11.439	....
	5	.384	.164	81.513	....
	6	.189	.312	17.655	....
Agny	1	.39	.682	19.799	....
	2	.251	.163	2.265	....
	3	.236	.135	2.095	....
	4	.38	.192	4.135	....
	5	.298	.246	5.20	....
	6	.30	.258	11.348	....
Auchy-lez-Hesdin	1	.221	.202	1.268	....
	2	.176	.239	47.327	....
	3	.208	.21	7.066	....
	4	.239	.125	4.61	....
Herbelles	1	.244	.097	.708	....
	2	.27	.114	.273	....
	3	.238	.093	.765	....
	4	.241	.201	43.37	....
	5	.206	.095	.586	....
	6	.336	.155	7.123	....
Beussent	1	.411	.187	16.211	....
	2	.241	.134	51.008	....
	3	.293	.084	2.564	....
	4	.369	.135	3.493	....
	5	.273	.096	.716	....
	6	.224	.116	5.975	....
Divion	1	.224	.084	.978	....
	2	.237	.124	3.626	....
	3	.167	.046	.434	....
	4	.257	.116	4.754	....
	5	.19	.096	.869	....
	6	.239	.176	2.583	....
Aix-en-Issart	1	.328	.091	.331	....
	2	.323	.142	.888	....
	3	.292	.116	.316	....
	4	.152	.307	36.02	....
	5	.259	.09	1.004	....
	6	.247	.167	6.025	....
Hermies	1	.40	.269	6.881	....
	2	.341	.167	6.882	....
	3	.327	.159	2.329	....
	4	.27	.17	4.729	....
	5	.289	.124	.561	....
	6	.269	.138	1.413	....
Chérisy	1	.202	.121	1.026	....
	2	.228	.34	23.132	....
	3	.336	.133	.924	....
	4	.322	.20	.975	....
	5	.259	.174	3.929	....
	6	.173	.162	.839	....
Guarbecque	1	.296	.10	1.245	....
	2	.337	.097	1.114	....
	3	.294	.13	2.24	....
	4	.302	.128	1.312	....
	5	.219	.065	.788	....
	6	.308	.106	2.146	....
Izel-les-Hameau	1	.202	.107	.646	....
	2	.219	.225	38.899	....
	3	.279	.121	1.975	....
	4	.26	.087	.618	....
	5	.209	.091	.808	....
	6	.303	.12	2.784	....
	7	.277	.111	1.671	....
Camiers	1	.125	.179	48.777	....
	2	.119	.07	2 05	....
	3	.329	.379	9.588	....
	4	.213	.089	1.746	....
	5	.181	.163	41.025	....
	6	.235	.144	68 206	....
	7	.156	.119	6 145	....
	8	.207	.089	.277	....
Le Transloy	1	.242	.081	.914	....
	2	.279	.122	.52	....
	3	.217	.093	.426	....

PAS-DE-CALAIS—Continued.

Description and locality.	Original sample No.	Potash (K₂O).	Phosphoric acid (P₂O₅).	Lime (CaCO₃).	Magnesium (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Le Transloy	4	0.219	0.118	0.537	....
	5	.254	.132	1.247	....
	6	.296	.121	.769	....
Blendecques	1	.26	.075	.877	....
	3	.186	.08	.175	....
	5	.133	.069	.289	....
	7	.205	.101	2.063	....
	9	.22	.203	11.44	....
	11	.192	.167	13.74	....
Fleurbaix	1	.321	.09	.997	....
	2	.34	.083	.94	....
	3	.372	.113	.739	....
	4	.358	.105	2.086	....
Bernieulles	1	.277	.083	.322	....
	2	.275	.079	5.241	....
	3	.239	.091	.854	....
	4	.221	.081	2.599	....
	5	.214	.089	1.053	....
	6	.339	.077	4.612	....
Duisans	1	.235	.111	1.348	....
	2	.361	.198	2.94	....
	3	.298	.089	.834	....
	4	.326	.12	.528	....
	5	.281	.158	1.989	....
	6	.209	.221	48.356	....
	7	.292	.126	5.413	....
Bucquoy (Essart)	1	.233	.08	6.333	....
	2	.275	.136	1.469	....
	3	.268	.146	.606	....
	4	.272	.135	.546	....
	5	.27	.133	.528	....
Louez	3	.291	.213	4.702	....
Ablainzevelle	5	.245	.172	.575	....
	6	.287	.132	.661	....
Frevent	8	.265	.088	1.069	....
Les Attaques	10	.226	.148	13.177	....
Ablainzevelle	11	.236	.096	.527	....
Oisy-le-Verger	13	.337	.094	1.367	....
Lumbres	14	.292	.108	2.378	....
	15	.212	.157	5.747	....
Lagnicourt	16	.343	.119	1.328	....
Bethune	17	.303	.144	1.59	....
Bapaume	19	.283	.105	.625	....
Campagne-les-Hesdin	21	.222	.103	.985	....
Fouquières	23	.231	.072	5.201	....
Bapaume	25	.223	.122	.775	....
Oignies	26	.206	.063	.586	....
Auchy-lez-La-Bassée	28	.238	.133	2.201	....
Oignies Les Chats-Huants	1	.18	.053	.455	....
Écoust-Saint-Mein	1	.258	.182	2.172	....
	2	.284	.124	.827	....
	3	.256	.128	.586	....
Bethune	1	.209	.09	1.379	....
	2	.224	.092	1.031	....

BOUCHES-DU-RHÔNE.[a]

La Crau	1	0.241	0.099	0.35	0.482
	2	.221	.088	.708	.382
	3	.204	.088	1.64	.498
	4	.177	.103	.464	.616
	5	.416	.128	1.588	.50
	6	.339	.091	.384	.56
	7	.491	.053	.972	.612
	8	.341	.197	12.00	.554
Limon de Durance	....	.26	.102	23.75	.833
		.252	.108	20.906	.989
		.353	.109	23.12	1.15
		.312	.104	20.777	.94
Limon du Rhône	....	.396	.118	23.05	.358
Sables du Rhône	1	.213	.112	31.50	.666
	2	.20	.101	32.40	.53
	3	.082	.094	16.83	.32
	4	.07	.078	18.30	.56
	5	.062	.069	19.30	.52
	6	.094	.104	19.80	.567

[a] Gastine. Ann. Sci. Agron., 1898, pp. 155, 240. Bul. Min. Agr. France, 1897, pp. 614–655.

Chemical composition of the soils of France—Continued.

BOUCHES-DU-RHÔNE—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime $CaCO_3$).	Magnesium (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Sables du Rhône	7	0.091	0.094	20.20	0.586
	8	.062	.069	24.50	.421
	9	.093	.078	22.50	.629
	10	.059	.101	23.60	.48
	11	.06	.077	21.41	.547
	12	.06	.093	27.65	.53
	13	.111	.135	18.40	.404
	14	.085	.15	34.45	.157
	15	.065	.129	22.10	.437
	16	.076	.124	22.15	.53
	17	.111	.15	21.45	.52
	18	.163	.148	22.10	.648
	19	.066	.078	17.30	.530
	20	.073	.096	17.56	.578
	21	.399	.13	30.30	1.657
	22	.198	.14	24.40	.684
	23	.129	.122	19.00	.731
	24	.21	.138	21.70	.462
	25	.078	.106	20.40	.547
	26	.085	.13	18.76	.478
	27	.085	.126	22.28	.58
	28	.074	.111	20.00	.334
	29	.316	.165	25.25	.892
	30	.181	.128	20.30	.606
	31	.153	.134	20.25	.597
	32	.222	.18	22.44	.714
	33	.236	.137	26.40	.86
	34	.075	.076	18.24	.612
La Camargue	1	.224	.159	31.87	1.136
	2	.212	.16	33.59	.944
	3	.419	.169	32.60	1.048
	4	.76	.155	34.50	1.387
	5	.545	.145	33.87	1.106
	6	.29	.145	33.97	1.162
	7	.418	.153	31.85	1.228
	8	.224	.139	32.40	1.518
	9	.183	.14	24.20	.875
	10	.217	.16	26.21	.94
	11	.249	.147	32.75	1.080
	12	.298	.15	32.22	1.039
	13	.412	.133	35.85	1.51
	14	.308	.14	29.80	1.107
	15	.268	.145	33.75	1.104
	16	.255	.14	32.50	.255
	17	.21	.125	31.92	1.201
	18	.278	.135	32.14	1.065
	19	.429	.16	30.95	1.013
	20	.152	.153	25.60	.992
	21	.374	.099	34.86	1.046
	22	.472	.108	32.90	1.096
	23	.547	.125	38.62	.974
	24	.437	.143	33.70	1.104
	25	.49	.138	34.70	1.042
	26	.525	.144	36.40	1.065
MARNE.[a]					
Verzy: Verzenay	21	0.171	0.205	14.50	0.007
	12	.186	.134	19.00	.036
	24	.237	.215	17.50	.011
	30	.115	.169	14.10	.009
Verzy	29	.205	.18	8.20	.003
	65	.136	.186	18.30	.007
	45	.19	.216	10.20	.043
	13	.169	.133	8.00	.034
	8	.135	.095	1.74	.091
Villers-Marmery	34	.241	.186	9.30	.092
	22	.219	.17	12.50	.101
	21	.278	.195	14.00	.106
	6	.252	.142	2.30	.086
	37	.258	.242	25.20	.139
	31	.18	.264	26.80	.097
	35	.168	.200	19.60	.048

[a] Müntz. Bul. Min. Agr., France, 1893, 170–210.

Chemical composition of the soils of France—Continued.

MARNE—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime $CaCO_3$).	Magnesium (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Ville-en-Tardenois: Pargny		0.186	0.153	32.10	0.164
		.168	.123	27.80	.137
		.246	.111	14.50	.288
		.246	.058	36.00	.288
		.23	.089	16.50	.205
		.144	.061	4.00	.106
Villedomange		.263	.165	9.30	.262
		.281	.13	13.30	.249
Courmas	1	.534	.094	30.50	.146
	2	.622	.08	22.50	1.124
Bouzy		.189	.161	11.35	.295
		.257	.14	8.85	.016

CHARENTE-INFERIEURE.[a]

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime $CaCO_3$).	Magnesium (MgO).
Perigny	1	0.434	0.089		
	2	.482	.142		
Chevillon	3	.778	.146		
	4	.379	.124		
	5	.742	.147		

LOIRE-INFERIEURE.[b]

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime $CaCO_3$).	Magnesium (MgO).
Nosay	1	0.07	0.08	0.07	0.07
	2	.05	.04	.05	.10
	3	.04	.04	.05	.04
	4	.10	.05	.13	.20
	5	.02	.07	.02	.02
	6	.05	.06	.09	.05
	7	.07	.03	.02	.08
	8	.13	.16	.09	.17
	9	.02	.17	.04	.02
	10	.07	.02	.09	.11
	11	.03	.09	.03	.05
	12	.11	.07	.11	.13
	13	.03	.05	.03	.03
	14	.05	.05	.03	.03
	15	.06	.15	.07	.03
	16	.10	.14	.12	.06
	17	.08	.12	.09	.14
	18	.08	.13	.07	.10
	19	.09	.15	.10	.16
	20	.12	.14	.12	.25
	21	.04	.08	.04	.04
	22	.11	.14	.09	.16
	23	.05	.10	.11	.06
	24	.04	.13	.11	.06
	25	.05	.13	.08	.06
	26	.06	.15	.04	.06
	27	.04	.11	.05	.01
	28	.11	.12	.07	.06
	29	.11	13	.04	.09
	30	.06	.09	.06	.05
	31	.04	.05	.04	.02
	32	.07	.08	.06	.05
	33	.06	.08	.09	.05
	34	.13	.11	.13	.05
	35	.08	.01	.07	.02
	36	.07	.03	.02	.01
	37	.05	.03	.02	.01
	38	.03	.04	.04	.03
	39	.05	.04	.06	.08
	40	.06	.10	.17	.11
	41	.04	.03	.06	.05
	42	.06	.03	.05	.06
	43	.04	.08	.03	.02
	44	.07	.05	.11	.04
	45	.05	.05	.07	.05
	46	.10	.06	.07	.06
	47	.18	.07	.04	.03
	48	.09	.13	.08	.05
	49	.06	.12	.05	.05
	50	.13	.14	.08	.04

[a] Verneuil. Prog. Agr. Viticole, 21, 491 (1894).

[b] Bul. Sta. de la Loire-Inférieure, 1900-01, 1903-4.

Chemical composition of the soils of France—Continued.

LOIRE-INFERIEURE—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime ($CaCO_3$).	Magnesium (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Nozay	51	0.12	0.12	0.11	0.10
	52	.10	.13	.11	.06
	53	.11	.10	.13	.05
	54	.15	.11	.12	.07
	55	.13	.10	.11	.05
	56	.11	.11	.11	.13
	57	.09	.09	.11	.06
	58	.12	.09	.07	.08
	59	.09	.10	.10	.09
	60	.11	.10	.10	.10
	61	.16	.13	.18	.07
	62	.09	.10	.10	.11
	63	.10	.12	.15	.14
	64	.09	.11	.08	.10
	65	.09	.06	.11	.23
	66	.03	.04	.04	.19
	67	.03	.05	.06	.21
	68	.04	.05	.06	.19
	69	.08	.11	.12	.39
	70	.13	.11	.15	.43
	71	.08	.08	.09	.25
	72	.07	.07	.06	.19
	73	.08	.06	.14	.25
	74	.14	.06	.07	.19
	75	.07	.06	.07	.15
	76	.09	.03	.11	.07
	77	.03	.02	.04	.04
	78	.05	.02	.06	.07
	79	.02	.02	.04	.04
	80	.04	.01	.05	.08
	81	.02	.01	.02	.05
	82	.06	.01	.06	.09
	83	.09	.05	.07	.05
	84	.03	.02	.03	.02
	85	.07	.08	.12	.04
	86	.11	.10	.13	.07
	87	.09	.06	.00	.04
	88	.12	.10	.15	.10
	89	.05	.05	.08	.04
	90	.05	.07	.08	.08
	91	.07	.02	.04	.05
	92	.04	.03	.04	.01
	93	.09	.08	.14	.11
	94	.06	.05	.08	.16
	95	.09	.05	.10	.05
	96	.13	.06	.14	.08
	97	.12	.08	.19	.11
	98	.11	Trace.	.02	.05
	99	.10	.05	.14	.07
	100	.14	.08	.09	.08
	101	.13	.06	.19	.10
	102	.12	.02	.14	.10
	103	.15	.08	.22	.16
	104	.12	.05	.19	.12
	105	.08	.09	.20	.14
	106	.06	.09	.10	.05
	107	.19	.10	.15	.12
	108	.07	.07	.11	.06
	109	.08	.11	.15	.10
	110	.13	.12	.16	.18
	111	.09	.12	.13	.12
	112	.04	.12	.31	.02
	113	.08	.10	.24	.07
	114	.09	.11	.15	.10
	115	.08	.09	.20	.11
	116	.10	.11	.20	.10
	117	.13	.13	.17	.12
	118	.06	.07	.19	.12
	119	.10	.13	.10	.12
	120	.15	.14	.14	.23
	121	.07	.09	.08	.04
	122	.03	.04	.04	.06
	123	.08	.12	.31	.11
	124	.05	.11	.23	.06
	125	.05	.15	.23	.08
	126	.07	.12	.13	.08
	127	.11	.10	.13	.15
	128	.12	.10	.10	.13
	129	.13	.14	.09	.08

Chemical composition of the soils of France—Continued.

LOIRE-INFERIEURE—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime ($CaCO_3$).	Magnesium (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Nozay	130	0.08	0.06	0.13	0.05
	131	.10	.14	.09	.06
	132	.20	.07	.15	.22
	133	.13	.05	.09	.12
	134	.06	.04	.05	.05
	135	.08	.07	.15	.06
	136	.06	.07	.07	.04
	137	.07	.08	.12	.07
	138	.09	.07	.12	.06
	139	.03	.03	.05	.02
	140	.02	.03	.04	.02
	141	.14	.09	.32	.12
	142	.07	.07	.09	.06
	143	.07	.11	.11	.06
	144	.05	.18	.62	.13
	145	.06	.09	.15	[illegible]
	146	.09	.04	.05	.06
	147	.12	.08	.18	.07
	148	.09	.04	.10	.21
	149	.08	.08	.13	.21
	150	.10	.04	.11	.13
	151	.10	.07	.09	.14
	152	.10	.07	.09	.11
	153	.08	.06	.06	.16
	154	.13	.03	.10	.16
	155	.13	.07	.18	.26
	156	.11	.05	12	.15
	157	.06	.02	.04	[illegible]
	158	.07	.05	.05	.10
	159	.07	.03	.08	.06
	160	.08	.02	.06	.05
	161	.12	.05	.08	.14
	162	.07	.09	.05	.09
	163	.09	.05	.05	.11
	164	.06	.02	.06	.08
	165	.08	.03	.08	.31
	166	,18	.04	.09	.28
	167	.04	.03	.05	.06
	168	.06	.07	.08	.07
	169	.04	.04	.08	.04
	170	.21	.06	.14	[illegible]
	171	.10	.07	.11	.30
	172	.13	.09	.20	.33
St. Viaud: Plessis-Grimaud (appx. 250 hectares)		.07	.08	.16	.13
		.21	.09	.17	.15
		.17	.04	.29	[illegible]
		.14	.04	.26	.16
		.12	.06	.16	.12
		.23	.08	.13	.21
		.21	.06	.10	.26
		.09	.06	.15	.06
		.17	.04	.16	.19
		.20	.09	.13	.14
		.24	.03	.35	.60
		.12	.06	.32	.23
		.14	.06	.18	.12
		.22	.08	.18	.31
		.19	.07	.12	.30
		.16	.07	.16	.24
		.21	.06	.18	.36
		.17	.05	.47	.37
		.10	.09	.16	.44
		.14	.05	.30	.23
		.14	.04	.24	.30
		.15	.06	.08	.14
		.21	.05	.30	[illegible]
		.15	.06	.15	.31
		.10	.05	.18	.34
		.16	.06	.27	.33
		.12	.04	.14	.15
		.18	.06	.11	.36
		.15	.08	.22	.15
		.10	.07	.39	.23
		.17	.08	.18	.15
		.15	.09	.33	.36
		.12	.04	.12	.36
		.11	.06	.12	.40
		.20	.06	.10	.12
		.09	.04	.07	.03

Chemical composition of the soils of France—Continued.

LOIRE-INFERIEURE—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime ($CaCO_3$).	Magnesium (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
St. Viaud: Plessis-Grimaud	....	0.10	0.10	0.06	0.04
	....	.18	.06	.08	.07
	....	.20	.06	.20	.09
	....	.18	.08	.12	.51
	....	.12	.04	.11	.72
	....	.15	.07	.21	.76
	....	.10	.06	.15	.54
	....	.11	.05	.12	.45
	....	.15	.06	.27	.39
	....	.20	.06	.12	.20
	....	.14	.08	.22	.17
	....	.12	.04	.06	.27
	....	.25	.08	.09	.20
	....	.12	.04	.05	.04
	....	.18	.07	.21	.36
	....	.20	.08	.10	.25
	....	.22	.06	.16	.34
	....	.12	.07	.09	.21
	....	.20	.06	.10	.12
	....	.22	.09	.18	.37
	....	.25	.06	.15	.31
	....	.25	.03	.17	.51
	....	.24	.07	.12	.11
	....	.22	.05	.09	.05
	....	.23	.07	.07	.09
	....	.21	.05	.09	.20
	....	.22	.07	.27	.10
	....	.15	.06	.10	.12
	....	.12	.05	.20	.15
	....	.13	.06	.19	.17
	....	.10	.04	.47	.13
	....	.14	.05	.13	.10
	....	.18	.06	.11	.09
	....	.17	.05	.33	.53
	....	.51	.04	.17	.12
	....	.16	.04	.18	.10
	....	.15	.04	.16	.09

HÉRAULT.[a]

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime ($CaCO_3$).	Magnesium (MgO).
Capestang: Alluvions de Capestang	1	0.131	0.095	15.164	....
	2	.114	.087	8.512	....
Murviel: Alluvions de l'Orb	3	.117	.132	2.918	....
Thézan	4	.158	.107	3.87	....
Lignan	5	.10	.07	.006	....
Sauvian	6	.172	.09	.437	....
Lignan	7	.149	.138	3.466	....
Beziers	8	.139	.146	5.60	....
	9	.131	.179	3.816	....
Villeneuve	10	.175	.134	2.635	....
	11	.182	.15	4.584	....
Lieuran: Alluvions de Libron	12	.134	.101	6.889	....
Beziers	13	.107	.071	1.38	....
Servian: Alluvions de la Tongue	14	.15	.137	6.364	....
	15	.171	.108	8.288	....
Saint-Thibery: Alluvions de l'Hérault	16	.171	.154	6.944	....
	17	.164	.155	7.224	....
Bessan	18	.195	.14	7.28	....
	19	.168	.20	7.112	....
Agde	20	.174	.167	8.344	....
	21	.20	.133	8.848	....
Agde: Sables des dunes	22	.047	.088	11.088	....
Lieuran: Diluvium de l'Epinouse	23	.167	.04	1.686	....
Servian	24	.143	.042	.003	....
Saint-Thibery	25	.192	.055	.431	....
	26	.076	.06	.781	....
	27	.147	.056	.896	....
Beziers	28	.135	.047	.706	....
Servian: Dépôts fluvio-volcaniques	29	.122	.26	3.147	....
Agde: Terrain pliocène	30	.258	.114	1.419	....
	31	.121	.082	17.64	....
Servian	32	.164	.081	3.214	....
Autignec: Terrain miocène	33	.102	.15	12.712	....
Murviel	34	.127	.095	6.72	....
Pomerols	35	.20	.119	10.92	....

[a] Lagatu and Semichon. Matériaux pour une Étude des Terres du Département de l'Hérault, 1893; Prog. Agr. et Vitu., 19, 105, 162, 179, 233, 276, 447, 489 (1893).

Chemical composition of the soils of France—Continued.

HÉRAULT—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime ($CaCO_3$).	Magnesium (MgO).
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Murviel	36	0.103	0.121	15.904	....
Beziers	37	.044	.052	15.848	....
Maureilham	38	.098	.157	15.344	....
Capestang	39	.134	.162	11.76	....
Pinet	40	.188	.054	17.304	....
Beziers	41	.105	.177	24.136	....
	42	.266	.136	28.836	....
Pinet	43	.212	.038	30.408	....
Beziers	44	.131	.092	14.84	....
	45	.236	.139	23.016	....
DORDOGNE.[a]					
Terrains granitiques	....	0.255	0.034	0.012	....
		.244	.0492	.0556	....
		.235	.046	.0491	....
				$CaCO_3$	....
Terrains crétacés	....	.08	.0796	16.00	....
		.069	.095	64.00	....
Sables du Périgord	....	.0612	.0256	Trace.	....
Saint-Nexans: Bouvées argilo-siliceuses	....	.1445	.0256	Trace.	....
Lunas: Bouvées silico-argileuses	....	.091	.022	Trace.	....
Lèves	....	.209	.069	2.24	....
Saint-Alvère	....	.075	.079	16.00	....
Landais: Terrains tertiaires	....	.097	.02	.119	....
		.195	.051	2.77	....
		.258	.056	2.24	....
		.319	.059	1.39	....
Terrains quaternaires	....	.15	.0703	.2225	0.125
		.189	.0615	.184	....
MEURTHE-ET-MOSELLE.[b]					
Cirey: Grès bigarrés	....	0.1717	0.0523	0.0364	0.075
Bertrichamp: Grès bigarrés	....	.0901	.0212	.028	.10
Marnes	....	.1819	.0559	.0532	.05
Argile	....	.1972	.0634	.1512	.08
HAUTE-PYRÉNÉES.[c]					
Vallée de Luz	1	0.455	0.123	0.0107	....
Prairie irriguée	2	.098	.202	.0171	....
Prairie tourbeuse	3	.097	.394	.082	....
Prairie sèche	4	.287	.128	.0137	....
EURE-ET-LOIR.[d]					
	206	0.096	0.069	0.84	0.148
	210	.081	.039	.39	.10
	212	.096	.051	.49	.092
	214	.105	.045	.91	.096
	216	.084	.056	1.09	.079
	220	.086	.036	.84	.066
	222	.076	.084	.53	.073
	224	.098	.061	5.60	.084
	226	.072	.06	.47	.075
	228	.079	.047	.42	.078
	230	.086	.051	.58	.086
ÉPERNAY.[d]					
Aoise: Mesnil-sur-Oger	1	0.178	0.186	28.95	0.025
	2	.169	.157	41.65	.093

[a] Ann. Inst. Nat. Agron. France, 14, 61 (1891-92).
[b] Bourgeois. Chaire departmentale d'agriculture. Rapports, 1891.
[c] Faure. Ann. Inst. Nat. Agron., 13, 117 (1888-91).
[d] Commission météorologique d'Eure-et-Loir, Rapports sur les champs d'experiences, 1891-1892.

There have been 1,550 samples reported upon from France with the extreme range for potash 0.02 to 1.30 per cent, phosphoric acid 0.01 to 7.14 per cent, lime 0.003 to 94.70 per cent, and magnesia 0.001 to 1.657 per cent.

Chemical composition of the soils of Germany.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
HESSE.[a]		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Buntsandstein	....	0.25	0.17	0.35	0.31
		.32	.13	.39	.38
		.31	.12	.37	.30
Basalt	....	.11	.15	.89	1.16
Grauwacke	....	.23	.18	.30	1.15
Muschelkalk	....	.14	.09	.52	1.75
"Taunusgesteine"	243	.15	.07	.10	.06
Devonien	411	.21	.02	.13	.08
"Rotliegendes"	67	.57	.12	3.16	1.13
Tertiary	6	.37	.10	14.97	1.76
	15	.37	.11	12.41	1.42
	1	.45	.05	20.20	.83
	5	.29	....	28.80	2.16
	3	.31	.12	5.55	.78
	19	.22	.30	13.60	.19
Diluvium	25	.38	.06	.38	.06
	58	....	.06	3.24	.08
	7	.19	.09	15.95	1.50
	8	.26	.26	6.85	1.05
	16	.22	.15	6.46	.45
	16	.11	.25	17.68	2.07
Alluvium	10	.35	....	2.12	.63
	21	.23	.14	3.41	.42
	20	.29	.25	4.73	.83
	12	.21	....	9.00	.87
PRUSSIA.[b]					
Köslin:[c]					
Koppenow	....	.094	.0709	.109	....
Zdrewen	....	.133	.0853	.2505	....
Dubberzin	....	.0936	.0603	.2243	....
Gross-Silber	....	.0572	.0657	.1991	....
		.0577	.0488	.1336	....
Reinwasser	....	.0524	.0881	.1292	....
Kl.-Spiegel	....	.069	.118	.05	....
		.076	.075	.067	....
Garden	....	.068	.037	.134	....
Neuhaus	....	.06	.044	.109	....
Helenenau	....	.065	.065	.095	....
Gr.-Raddow	....	.044	.06	.082	....
Landechow	....	.083	.089	.156	....
Schinz	....	.038	.053	.035	....
Breitenberg	....	.058	.099	.185	....
Schmolsin	....	.03	.079	.072	....
Gr.-Mellen	....	.026	.092	.048	....
Knick	....	.03	.072	.15	....
WEST PRUSSIA.[d]					
Kainozoic	....	.061	.105	.182	.422
		.065	.096	.147	.199
		.068	.094	.153	.175
		.052	.094	.14	.154
		.049	.098	.14	.137
		.027	.09	.233	.163
		.039	.053	.171	.059
		.078	.133	5.783	.261
		.037	.069	.087	.044
		.078	.106	.898	.333
		.061	.065	.70	.103
		.061	.042	.847	.43
		.092	.054	.20	.028
Mesozoic	....	.039	.018	.683	.042
		.066	.053	.343	.103
		.103	.03	2.507	.533

[a] Habernoll, Mitt. Landw. Inst. königl. Univ. Breslau, 2, 147 (1899). Haselhoff, Fühlings landw. Ztg., 55, 73 (1906).

[b] Baessler, Ber. Thät. Agrik.-Chem. Versuchs-und Samencontrolstation, Köslin, 1897, 1899.

[c] The potash analyses were made with 10 per cent hydrochloric acid. The phosphoric acid and lime results are based upon complete analyses.

[d] Wohltmann, Das Nahrestoff-Kapital west-deutscher Böden, Bonn, 1901. Analyses with cold hydrochloric acid.

Chemical composition of the soils of Germany—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
WEST PRUSSIA [a]—continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Mesozoic		0.113	0.025	22.067	0.113
		.031	.06	3.24	.202
		.039	.021	.183	.144
		.056	.045	.347	.084
		.039	.047	.127	.096
		.05	.083	.027	.017
		.077	.115	.28	.065
		.047	.169	.386	.048
Paleozoic		.135	.058	4.403	.216
		.144	.171	2.60	.37
		.026	.034	.087	.019
		.188	.235	.297	.659
		.123	.192	1.63	.144
		.04	.028	Trace.	.019
		.129	.092	.293	.072
Eruptive rocks		.179	.041	.753	.176
		.212	.209	1.849	.574
Humus soils	3	.14	.22	1.03	
	8	.34	.44	2.85	
	13	.10	.13	1.40	
	21	.05	.29	2.37	
Heavy soils	5	.15	.35	1.91	
	7	.48	.13	.88	
	9	.21	.32	.77	
	11	.17	.11	.19	
	17	.30	.09	.86	
	20	.17	.12	.84	
	22	.75	.13	1.77	
	23	.23	.11	.41	
	27	.58	.13	.67	
	28	.25	.10	.31	
	29	.18	.09	.44	
Medium soils	1	.17	.09	.38	
	2	.11	.08	.19	
	12	.13	.05	.40	
	14	.17	.08	.35	
	18	.16	.12	.27	
	24	.16	.09	.17	
	25	.09	.09	.16	
	26	.19	.16	6.40	
Light soils	4	.21	.10	.18	
	6	.11	.23	.43	
	10	.04	.19	.11	
	15	.07	.08	.13	
	16	.07	.09	.18	
	19	.07	.09	.26	
	30	.08	.10	.17	
Westphalia [b] Lünten Dömern	1	.047	.016	.076	
	9	.063	.036	.128	
	20	.265	.028	.077	
	4	.049	.022	.157	
	3	.419	.061	.571	
	2	.074	.016	.157	
	18	.024	.016	.225	
	11	.148	.023	.152	
	5	.304	.015	.081	
	13	.129	.019	.251	
	22	.031	.019	.178	
	24	.025	.026	.192	
	25	.03	.011	.103	
	26	.066	.029	.40	
	7	.149	.04	.027	
	8	.05	.012	.017	
	16	.256	.01	.025	
Wettringen, Bilk, and Haddrup:					
I (a)	0	.029	.03	.097	.063
	3	.033	.018	.192	.045
	5	.051	.003	.133	Trace.
	8	.019	.011	.007	Trace.
	9	.04	.01	.007	Trace.
	15	.019	Trace.	.079	.048
I	0	.092	.02	.036	.032
	1	.063	.009	.20	.032

[a] Schmoeger Landw. Jahrb., vol. 34, p. 160 (1905). Blanck, Landw. Vers.-Sta., 60, 407 (1904). The first two soils were treated with hot concentrated hydrochloric acid. The following five soils were treated with double-strength hydrochloric acid, and for the last two soils complete analyses are given.

[b] Haselhoff and Breme. Die Haideböden. Westfalens, 1899 to 1903.

Chemical composition of the soils of Germany—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
WEST PRUSSIA—continued					
Wettringen, Bilk, and Haddrup—Con.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
I......	4	0.04	0.021	0.01	0.029
	9	.024	.021	.029	.031
	11	.009	.003	.05	.036
	16	.014	.092	.125	Trace.
	19	.033	.029	.148	.043
	31	.019	.044	.255	.025
II......	1	.019	Trace.	.075	.039
	2	.01	.070	.126	.071
	5	.033	.022	.097	.016
	6	.032	.01	.203	.00
	12	.069	.00	.00	.00
	16	.023	.016	.056	.00
	21	.023	.016	.089	.00
	25	.051	Trace.	.032	.01
III......	1	.049	.014	.143	.003
	2	.025	.008	.00	.018
	5	.057	Trace.	.072	.035
	10	.04	.005	Trace.	.033
	13	.018	.006	.18	Trace.
IV......	1	.019	.00	.01	.00
	5	.024	.014	.003	.024
	10	.05	.007	.138	.004
V......	1	.013	.006	.176	.025
	3	.014	.017	.182	.014
	5	.066	.066	.058	.20
	8	.014	.00	.139	.031
VI......	1	.028	.03	.014	.008
	2	.024	.018	.028	.014
	6	.016	.023	.286	.083
VII......	2	.016	.015	.021	.021
	7	.019	.015	.261	.008
	16	.008	.012	.025	.007
	22	.027	.014	.05	Trace.
VIII......	1	.022	.11	.05	Trace.
	8	.014	.056	.075	.023
	12	.038	.031	.072	.028
	16	.027	.007	.01	.016
	20	.028	.018	.063	.002
IX......	2	.091	.066	.063	.102
	12	.05	.026	.043	.099
	14	.023	.00	.041	.081
	20	.029	.00	.061	.092
	21	.032	.00	.075	.037
	28	.036	.028	.083	.018
	32	.049	.013	.065	.017
X......	4	.027	.016	Trace.	.031
	9	.061	.014	Trace.	.014
	13	.044	.023	.155	.004
	16	.053	.013	.075	Trace.
Handorf and Telgte..........................	13	.008	.071	.112	.018
	6	.075	.012	.023	.008
	1	.057	.019	.077	.022
	2	.088	.032	.135	.017
	3	.026	.025	.119	.005
	5	.012	.038	.00	.008
	10	.106	.028	.114	.032
	15	.127	.051	.046	.129
	20	.114	.053	.165	.131
	1	.103	.041	.023	.17
	8	.037	.043	.112	.123
	10	.05	.032	.096	.037
	18	.068	.097	.092	.08
	20	.025	.16	.16	.14
St. Mauritz, Gelmer, and Gimbte............	3	.023	.039	.365	.062
	4	.129	.027	.178	....
	5	.071	.028	.042	Trace.
	7	.01	.039	.543	.045
	8	.201	.028	.337	.094
	9	.086	.036	.117	.00
	12	.157	.058	.154	.02
	12	.053	.024	.348	.00
	15	.093	.04	.138	.01
Wiedenbrück................................	1	.054	.021	.12	.113
		.083	.053	.348	.053
		.083	.062	.288	.079
		.073	.07	.961	.278

Chemical composition of the soils of Germany—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
WEST PRUSSIA—continued.					
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Wiedenbrück—Continued		0.06	0.032	0.106	0.049
	2	.073	.006	.075	.021
	5	.115	.024	.14	.054
	6	.045	.011	.063	.023
		.009	.022	.048	.017
	8	.148	.011	.418	.082
		.023	.078	.183	.076
	9	.146	.10	.105	.061
		.048	.027	.194	.045
	14	.006	.009	.052	.01
		.022	.059	.088	.031
	17	.004	.016	.073	.027
		.004	.023	.116	.032
	18	.014	.032	.174	.191
	19	.025	.037	.091	.028
		.006	.031	.079	.02
	20	.051	.066	.205	.013
		.021	.034	.113	.014
		.017	.029	.08	.015
	21	.02	.029	.04	.03
		.101	.03	.165	.012
	22	.092	.013	.03	.009
		.018	.018	.21	.026
	23	.040	.029	.04	.036
		.064	.014	.061	.011
	24	.043	.027	.12	.01
		.017	.085	.048	.015
		.088	.024	.093	.054
		.157	.015	.078	.032
	25	.07	.034	.085	.016
		.021	.08	.012	.015
	26	.030	.014	.028	.011
		.014	.064	.038	.009
	27	.042	.009	.063	.022
		.123	.014	.08	.035
	28	.019	.016	.14	.02
		.033	.032	.23	.002
		.061	.022	.51	.058
	29	.041	.015	.035	.003
		.076	.006	.048	.006
	30	.085	.01	.028	....
		.04	.011	.023	....
	31	.024	.021	.073	.035
	32	.033	.041	.09	.038
	35	.052	.038	.07	.042
		.042	.023	.10	.027
		.056	.026	.178	.034
		.029	.008	.035	.019
	37	.058	.019	.08	.016
	39	.025	.022	.023	.013
	40	.051	.021	.04	.006
	42	.035	.009	.02	....
		.06	.032	.025	.022
		.016	.035	.15	.02
	43	.013	.029	.143	.021
	46	.099	.013	.043	.014
	47	.032	.018	.055	.011
	48	.047	.035	.043	Trace.
	50	.053	.019	.045	
		.062	.029	.04	.014
	51	.051	.003	.045	.009
		.126	.032	.085	.001
	52	.165	.012	.088	.005
		.041	.013	.062	.023
		.031	.009	.074	.009
		.015	.027	.123	.007
	53	.03	.066	.055	.005
		.063	Trace.	.012	Trace.
	54	.042	.005	.023	....
	56	.036	.006	.09	.007
	57	.034	.011	.11	Trace.
		.048	Trace.	.038	Trace.
	58	.008	.021	.12	Trace.
	59	.079	.006	.005	Trace.
	61	.091	.021	.013	.007
	62	.065	.008	.01	Trace.

Chemical composition of the soils of Germany—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
WEST PRUSSIA—continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Arendsee[a]	1	0.055	0.048	0.343	0.041
Wessnig[a]	2	.116	.158	.317	.132
Harpe[a]	3	.074	.072	.912	.048
Schurigshof.[a]	4	.094	.05	.285	.074
Schwemsal[a]	5	.191	.093	.563	.342
Lauchstädt[a]	6	.446	.084	.984	.52
Vitzenburg[a]	7	.339	.148	5.75	1.666
Wessnig[a]	8	.167	.08	.503	.338
	9	.510	.814	4.019	1.257
	10	.277	.158	.81	.836
EAST PRUSSIA		.3336	.1180	1.059	.2026
		.3486	.1113	1.093	.1529
		.68	.09	.41	1.16
		.81	.18	.48	1.87
		.14	.13	.50	1.17
		.15	.11	.38	.79
		.34	.11	1.08	.18
		3.10	.252	1.99	1.09
		3.23	.245	1.82	1.18
OLDENBURG.[b]					
Marsh soils	1	2.23	.25	4.34	1.66
	2	2.14	.21	4.24	1.41
	3	.73	.21	5.86	1.71
	4	.89	.18	6.57	1.81
	5	.62	.23	7.09	1.85
	6	.26	.12	.43	
	7	.17	.08	2.52	
	8	.45	.05	.10	
	9	.41	.13	.14	
	10	.43	.26	.50	
	11	.44	.15	3.28	
	12	.39	.11	3.28	
	13	.62	.06	.11	
	14	.44	.18	.19	
	15	.44	.11	.24	
	16	.38	.16	.28	
	17	.46	.10		
	18	.33	.13		
	19	.24	.10	.21	
	20	.62	.12	.95	
	21	.37	.11	.42	
	22	.38	.13	.39	
	23	.33	.09	.33	
	24	.33	.16	1.53	
	25	.82	.16	1.26	
	26	.46	.11	1.16	
	27	.57	.14	.78	
	28	.54	.18	.39	
	29	.32	.10	.69	
	30	.43	.12	2.40	
	31	.49	.12	.46	
	32	.55	.20	.46	
	33	.56	.19	.47	
	34	.60	.19	.49	
	35	1.00	.28	4.99	
	36	.18	.08	4.48	
	37	.39	.11	.52	
	38	.35	.10	.46	
Blauhandter Groden		.59	.151	2.27	
Ellenserdammer Groden		.66	.152	3.87	
Friedrich August Groden		.68	.193	4.88	
Adelheids Groden		.62	.235	5.16	
Peters Groden		.56	.25	5.28	
BAVARIA AND WURTTEMBERG.[c]					
Moor soils	608	.091	.276	4.82	
	597	.077	.272	3.51	
	610	.099	.256	2.77	
	609	.088	.34	2.13	
	612	.046	.183	1.50	

[a] Schneidewind. Meyer, and Frese. Landw. Jahrb., 35. 927 (1906). Analyses made with 10 per cent hydrochloric acid, except in the case of phosphoric acid, where complete analyses are given.

[b] Schucht. Jour. Landw.. 53. p. 322 (1905). Maercker. Zusammensetzung und Düngerbedürfnis Oldenburg Marscherden und deren Bewirtschaftung. Berlin, 1896.

[c] Vierteljahresschr. bayer. Landw.-Rat, 10, Ber. Arbeiten Moorkult, 1904.

Chemical composition of the soils of Germany—Continued.

Description and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
BAVARIA AND WURTEMBURG—continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Moor soils	611	0.056	0.266	1.20	....
	613	.060	.243	.921	....
	232	....	.185	2.85	....
	233	.237	.211	1.19	....
	234	.1265	.397	1.25	....
	235	.067	.165	.471	....
	69	.0754	....	....	....
	248	.0761	.139	.529	....
	223	.0611	.119	.387	....
	219	.0669	.146	.681	....
	243	.0738	.147	.506	....
	246	.0665	.122	.338	....
	224	.0565	.156	.454	....
	451	.0517	.127	.459	....
	242	.0638	.133	.557	....
	241	.0588	.121	.331	....
	249	.0478	.085	.61	....
	452	.0645	.142	.341	....
	453	.0682	.127	.254	....
	222	.0496	.117	.397	....
	454	....	.107	.325	....
	247	.0467	.129	.421	....
	244	.0508	.094	.377	....
	220	....	.069	.168	....
	221	....	.094	.535	....
	237	.0365	.076	.368	....
	245	.0386	.106	.214	....
	239	.032	.093	.371	....
	240	.0307	.085	.516	....
	236	.028	.066	.344	....
	238	.0238	.061	.333	....
	580	.116	.097	.36	....
	581	.097	.098	.404	....
	593	.075	.125	.28	....
	594	.074	.151	.257	....
	592	.065	.106	.439	....
	585	.076	.152	.272	....
	589	.0586	.121	.217	....
	591	.0457	.135	.306	....
	595	.064	.114	.228	....
	577	.063	.18	.24	....
	586	.074	.153	.356	....
	578	.078	.164	.29	....
	583	.056	.108	.289	....
	575	.050	.194	.32	....
	572	.061	.146	.312	....
	579	.047	.162	.336	....
	587	.0451	.117	.259	....
	576	.041	.129	.298	....
	574	.046	.127	.367	....
	588	.043	.113	.265	....
	584	.042	.068	.318	....
	590	.037	.092	.517	....
	582	.033	.096	.313	....
	573	.021	.121	.401	....
	544	.0794	.184	.383	....
	542	.0587	.152	.39	....
	1076	.0668	.259	.535	....
	547	.0673	.206	.826	....
	540	.0629	.156	.89	....
	541	.0535	.119	.425	....
	536	....	.164	.419	....
	1074	.058	.217	.423	....
	1071	.063	.182	.58	....
	539	.0482	.158	1.02	....
	537	....	.106	.40	....
	538	.0473	.083	.615	....
	543	.039	.139	.825	....
	546	.0293	.074	2.73	....
	1073	.042	.20	.576	....
	1075	.054	.207	.078	....
	1072	.041	.177	.906	....
	545	....	.094	.742	....
Loess soils[a]	1	.15	.16	14.95	0.9
	2	.12	.13	14.10	1.
	3	.13	.13	12.50	1.
	4	.14	.18	16.76	Trace.
	5	.12	.09	10.26	.0

[a] Halenke, Kling and Engels, Vierteljahressch. bayer. Landw.-Rat, 10, 447 (1905).

Chemical composition of the soils of Germany—Continued.

Descriptioh and locality.	Original sample No.	Potash (K_2O).	Phosphoric acid (P_2O_5).	Lime (CaO).	Magnesia (MgO).
BAVARIA AND WURTEMBURG—continued.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Loess soils	6	0.18	0.14	12.20	Trace.
	7	.13	.11	16.40	0.29
	8	.20	.15	17.80	.93
	9	....	....	47.00	.46
Middle-sandstone soils[a]	1	.06	.05	.09	.05
	2	.05	.04	.05	.04
	3	.06	.07	.17	.19
	4	.06	.09	.19	.14
	5	.03	.02	.02	.02
	6	.09	.09	.00	.27
	7	.19	.05	.014	.08
	8	.17	.18	.25	.09
	9	.13	.34	.52	.15
North German plain loess[b]	....	2.33	....	6.6	1.37
		2.47	....	.59	.25
		.81	....	.50	.17
		2.58	....	.80	.72
		2.57	....	.43	.70
Highland	....	.109	.115	.064	.238
		.41	.068	.29	.64
		.026	.08	.072	.075
		.102	.03	.242	.161

[a] Blanck, Landw. Vers.-Sta., 65, 161 (1906).

[b] Burguy, Über die Bödenverhaltnisse des norddeutschen Flachlandes in ihrer Beziehung zum geologischen Aufbau desselben. Inaug.-Diss. Berlin, 1899.

There have been 449 samples reported upon from Germany with the extreme range for potash 0.003 to 3.23 per cent, phosphoric acid 0.003 to 0.814 per cent, lime 0.003 to 47.0 per cent, and magnesia 0.001 to 2.16 per cent.

CONCLUSIONS.

A careful study of the data which have been presented appears to justify two conclusions.

First. That the productivity of the newer agricultural soils of the United States and of the older agricultural soils of Europe, taken as a whole and for a nation, are not declining, as is popularly supposed. Individual farms deteriorate and soils wear out as they have always done, but as a whole it seems probable that we are producing more crops per acre than formerly. This is undoubtedly due to many factors; to better and more intelligent cultivation, more and better systems of rotation of crops, and, in later years, to intelligent use of fertilizers—three methods of control in the hands of every individual farmer. In addition, we must recognize the increase in farm animals and stock, the improvement in seed by selection and breeding, and the increasing density in population, which is forcing attention to more intensive methods.

Second. That so far as our information goes there is apparently no significant difference at the present time between the composition of the older agricultural soils of Europe and the newer agricultural soils of the United States with respect to potash, phosphoric acid, lime, and magnesia.

O

Issued May 10, 1910.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS—BULLETIN NO. 58.
MILTON WHITNEY, Chief.

THE COMPOSITION OF COMMERCIAL FERTILIZERS.

BY

MILTON WHITNEY.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1910.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS,
Washington, D. C., April 27, 1909.

SIR: I have the honor to transmit herewith the manuscript of an article on The Composition of Commercial Fertilizers, and to recommend that this be published as Bulletin No. 58 of the Bureau of Soils.

Respectfully

MILTON WHITNEY,
Chief of Bureau.

Hon. JAMES WILSON,
Secretary of Agriculture.

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THE COMPOSITION OF COMMERCIAL FERTILIZERS.

The foundation of the material wealth of this nation and its position among the nations of the world is the productive capacity of its soils, and, under favorable climatic conditions, there are three principal methods of controlling this productive capacity. These are cultivation, including drainage and irrigation; rotation of crops, and fertilization. Of these, cultivation and rotation are in the hands of the farmer himself. Fertilizing materials, however, have, to a very large extent, to be gathered for him from different parts of the world and manipulated to some extent before they are ready to be applied to the land. It is with these manipulated materials containing two or more valuable ingredients, known as "mixed goods," that this bulletin will deal. It is generally believed that simple fertilizers, such as muriate of potash, nitrate of soda, or plain superphosphates, when used alone are neither as safe nor as efficient as when used in combination, and as they can usually be mixed more thoroughly by machinery and more cheaply in large quantities, the practice has grown up of buying them ready mixed from dealers or manufacturers.

The character of the materials which can profitably be used in these mixtures and the proportions in which the valuable constituents should be contained for the best results for different soils and crops have been a perplexing problem for the manufacturer as well as for the farmer, and have been the subject of much investigation by the experiment stations for the past half century.

As a result of the investigations of the experiment stations, we know a fair number of fertilizer materials which can be obtained at prices justifying their application to soils to which they give a moderate increase in crop production. On account, however, of their uncertain action, due largely to seasonal differences and changing soil conditions, and of our lack of knowledge as to just how they act on the soil or on the plant, we still have little exact knowledge of the kind of material adapted to different soils or crops or the proportions in which the several ingredients should be combined.

Pending the results of further investigations to settle these vitally important problems, most of the States have very efficient systems of fertilizer inspection, by which, mainly through chemical analyses, the farmer may determine whether he is paying more for a commercial fertilizer than he would pay if he purchased simple fertilizer recent of the standard books on fertilizers[a] asserts in the most cautious way and with many qualifications that corn is particularly responsive to phosphates, cereal crops to nitrates, grasses and clovers to phosphoric acid and potash, beets and carrots to nitrogen, potatoes and sweet potatoes to potash, and truck crops to nitrogen; and yet with only this meager information, not pretending to be exact or invariable, we find a multitude of brands on the market, many of them being prepared and recommended for special crops. One has but to look up the reports of the state departments of agriculture and the state experiment stations charged with the inspection of fertilizer materials to see the absolute lack of system which prevails in the fertilizer trade. The tendency in this country seems to run to an increase in the number of special brands for special crops, but there is an absolute lack of uniformity even in the elementary composition of these special brands. As a rule the fertilizer formulas are simpler and more uniform in the South than they are in the North; there are also a less number of special brands for special crops. For example, there are very few fertilizers for special crops offered in the States of Alabama and Georgia. In North Carolina about 28 per cent of the whole number of brands of fertilizers sold in the State are recommended for special crops. In Connecticut 45 per cent of the whole number of brands sold are special brands for special crops. In the State of Georgia there were 1,822 brands inspected, analyzed, and placed upon the market for sale in 1908. Of these, 1,260 brands contained two or more of the plant-food elements (phosphoric acid, nitrogen, or potash), in 106 different combinations, as shown on the guarantees; 1,143 of these brands, or 90 per cent, contained six or more identical guarantees covered by 26 combinations. There were 238 brands, or 24 per cent, of the complete fertilizers which contained 10 per cent phosphoric acid, 2 per cent of ammonia, and 2 per cent of potash. There were 242 brands, or 26 per cent, which contained 8 per cent of phosphoric acid, 2 per cent of ammonia, and 2 per cent of potash. If these brands differ in the material of which they are composed, the farmers should know this in order that they can make a more intelligent selection for their particular soils and crops, but there is no way in which they can find out whether they differ or not. It is also to the interest of the manufacturer to have this known, so that the farmers can make a more intelligent selection of their goods. The brands undoubtedly differ in effectiveness by reason of the materials which they contain, and we are sadly neglecting our opportunities of developing our agricultural practice by failure to know the materials they actually do contain. Of the 33 special brands for tobacco placed on sale in the State of Connecticut, phosphoric acid ranges from 3 to 9 per cent, ammonia from 2 to 7½ per cent, and potash from 2 to 11 per cent. There are 24 different combinations in the 33 brands issued for this special crop, which is grown on a very limited extent of the soils of the State. Instances of this kind could be multiplied almost indefinitely, and there is submitted with this report an appendix giving a very complete analysis of the figures relating to the fertilizers on sale in three of the Southern States, namely, Alabama, Georgia, and North Carolina, where the fertilizer control is under the state department of agriculture, and three of the Northern States, namely, Maine, Massachusetts, and Connecticut, where the fertilizer control is vested in the state experiment stations. These figures, together with the opinions of some of the recognized authorities on commercial fertilizers, will be found in the appendix in this report.

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[a] "Fertilizers," by Edward B. Voorhees, 1902.

Most of the States regulate by law or by executive order under authority of the law material which may or shall not be used in commercial fertilizers and words which may be printed or stamped on the brands. Thus the State of Georgia prohibits the use of the word "standard" in connection with a brand containing less than the commercial equivalent of 8 per cent of phosphoric acid, 2 per cent of ammonia, and 2 per cent of potash, and of the words "high grade" on any fertilizer containing less than the commercial equivalent of 10 per cent phosphoric acid, 2 per cent ammonia, and 2 per cent potash, although both of these combinations are far below the combinations recommended by the state department of agriculture.

It is the general belief at the present time that a fertilizer for tobacco should be rich in potash and that for cigar tobacco the potash should be in the form of carbonate, yet we find in Connecticut special brands for tobacco with from 1 to 3 per cent of potash, and so far as the evidence permits one to judge the potash in the majority of brands is not in the form of carbonate. It would seem that it would be a protection to the farmers to prohibit the use of the word "tobacco" on a brand of fertilizer containing less, say, than 6 per cent of potash in the form of carbonate only.

It is the general belief that potatoes require fertilizers rich in potash and that it is better to have the potash in the form of sulphate, yet we find brands of special fertilizers for potatoes offered for sale in Maine with only 2 and 3 per cent of potash. It would be a protection to the farmers to prohibit the use of the word "potatoes" on any special brand for potatoes with less than a minimum of, say, 6 per cent of potash, and this in the form of sulphate only.

It is held by the Maine Experiment Station[a] that nitrogen for potatoes should be in the form of nitrate nitrogen, and yet, even in that State, the principle is not enforced by law and the nitrogen supply in the special brands for potatoes is of such form as may be determined by the manufacturer. It is the general belief that sugar beets require a fertilizer rich in potash and that it is best to have this in the form of chloride or muriate, but no particular attention seems to be paid to this in the preparation of special brands and the farmers do not know what materials they are purchasing.

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[a] Bul. 153, Maine Agr. Expt. Sta., March, 1908, p. 105.

For about twenty years the experiment stations were very active in conducting and reporting the results of plat experiments with fertilizers, but lately very little of such work has been reported. There are a few notable exceptions where long-time experiments are yet in progress, but for the most part such work is considered of merely local interest or the attention of the station has been directed to other apparently more pressing needs.

There is yet so much to be learned of the action of fertilizers to establish a rational system that it is very desirable that investigations of this important subject shall be more vigorously pushed in the future, both along the line of field plat tests and along such other lines as may promise valuable results bearing on the theory and practical use of commercial fertilizers.

APPENDIX A.

EXTRACTS FROM OFFICIAL REPORTS AND STANDARD BOOKS ON FERTILIZERS.

The following extracts do not pretend to be a complete résumé of the literature on fertilizers, as this is very voluminous, but only to give a few striking statements from recognized authorities on the points which have been made in the preceding report:

In its work in connection with commercial fertilizers, in detecting and driving out frauds, placing the trade on a rational basis, encouraging honest manufacturers and sellers, and teaching farmers how to select their fertilizers wisely and use them with profit, its [the experiment-station's] usefulness can not be overestimated.

First Annual Report, Conn. Agr. Expt. Sta., 1876, prefatory note, p. 3.

The means adopted by the station to regulate the sale of fertilizers in the State have been explained quite fully in Circular No. 4 of the station. * * *

The plan is substantially the same as has, with various modifications of detail, come into quite general usage in Germany and other European countries. The essential features are:

First. An agreement made with the station by dealers in fertilizers to sell their wares by guaranteed analysis, the verification of the analysis being left to the station; and,

Second. A provision whereby purchasers may have samples of the articles they buy analyzed by the station at small cost, or for nothing.

In order to preclude all chance for mistake or cavil, as to the precise terms of the arrangement referred to, a form of agreement has been signed by the dealers who desired to place their wares, as sold in the State, under the supervision of the station.

The form referred to is the result of the deliberations of a large meeting of manufacturers, sellers, and consumers of fertilizers, held at the station, and of consultation with the Advisory Committee and with other parties interested. It is as follows:

Blank B.

———— hereby agree with the Connecticut Agricultural Experiment Station, as represented by its directors, that all fertilizers offered for sale in the State of Connecticut by ———— or by ————, authorized agents, at any price above fifteen dollars ($15.00) per ton, except crude fish-scrap, shall be placed under its supervision in the following manner:

1. ———— hereby agree that all fertilizers above described shall be guaranteed to contain certain minimum percentages of one or more of the following ingredients:

Nitrogen.
Phosphoric acid; soluble.
Phosphoric acid; reverted.
Phosphoric acid; insoluble.
Potash.
Sulphuric acid; chlorine.

* * * * * * *

2. ———— also agree that the above guarantee shall be always subject to verification by analyses made at the stations.

3. ———— also agree that all fertilizers above described shall be at all times open to the inspection of the station, as represented by its Director, Chemists, or any member of its Advisory Committee. * * *

The signer of this agreement is not expected to specify in this blank the composition of the wares he sells, but he does bind himself to fulfill the requirements of the state law, by accompanying every package of fertilizer sold with a plain statement of the analysis, using the above terms, and to guarantee the article to be equal to the analysis.

In brief, this agreement binds the signer simply to state what he sells and guarantee what he states, the verification of the statement being left to the official analysis of the station. With the fulfillment of this guarantee the responsibility of the seller will naturally end. The station provides that buyers who wish to determine whether the articles they purchase are equal to the guarantee, may have control analyses made at little or no expense. It is believed that no simpler nor more efficient way can be devised to place the trade in fertilizers on a more secure basis, insure confidence, and benefit all concerned.

First Annual Report, Conn. Agr. Expt. Sta., 1876, pp. 14-16.

The question as to which is the most serviceable and best fertilizer is like the question, which is the best and most serviceable medicine—impossible to answer. All depends on the patient, on what ails him, and on how he is being treated otherwise.

The experiment station might be compared to a sanitary engineer, but not to a practicing physician. We are unable to prescribe for land. The only way is for the practical farmer to make trials on his land with fertilizers or fertilizing chemicals which he knows are of good quantity [quality?] and study the effects. * * *

There is a choice also in respect to action on the crop. This will depend somewhat on the character of your soil and can only be learned by experience. One fertilizer will appear to be best one year or on some crops and land, and another season, owing to the different weather, wet or drought, or on other land or plants, another kind of fertilizer will give the best results. I should try a fertilizer that would give me *a good percentage of nitrogen, soluble phosphoric acid, and potash for the least money.*

We can give no formula for an onion manure. The food which the onion requires is the same that all other crops require. If it requires any special proportions of fertilizing ingredients, neither we nor any one else can positively say what that is. Probably a fertilizer having about the composition of the "special" onion, potato, tobacco, or corn manures would be as profitable a fertilizer as you could apply to the onion. * * *

It is a fact of common farm experience that nitrogenous manures differ widely in their efficiency. Nitrate of soda, for example, often has a visible effect on grass land within ten days after sowing; dried blood requires a longer time to affect the color or growth of grass, while an application of leather or hair may never show the slightest effect. * * *

A considerable number of manufacturing wastes, rich in nitrogen, but differing greatly in their value as plant foods, are now on the market, and their use is urged upon manufacturers of mixed fertilizers. In general, such of these waste products as are agriculturally of least value are also least expensive, and therefore the temptation to use them in manufactured goods is to some very strong.

It is highly desirable to know in the first place how these nitrogenous wastes compare with each other, and with some standard, such as nitrate of soda, in availability, and various experimenters have already accomplished something in this direction. In the next place it is important, either to be able to identify these various "ammoniates" in mixed fertilizers, or else to have some means of distinguishing in such fertilizers between available and inert nitrogen—some measure of its availability. Unfortunately, it has hitherto been difficult or impossible to identify with certainty most of the inferior ammoniates either by inspection or by ordinary chemical tests. The treatment with acid during the process of manufacture, the grinding and the mixture with phosphatic material and potash salts, so alters the structure and appearance that in many cases the microscope fails to identify anything and chemical tests are not generally applicable.

Annual Report Conn. Agr. Expt. Sta., 1885, pp. 110-116.

We have reason to believe from extended observations and experience in the field that hundreds of thousands of dollars are annually wasted by farmers in the lavish and injudicious application of fertilizers on cotton.

Fertilizers for Cotton, J. M. McBryde, Farmers' Bulletin 14, 1894, p. 7.

The author shows that the different forms of phosphates and the different materials used to supply nitrates vary greatly in their efficiency.

"The most satisfactory, and, indeed, usually the only method," says Armsby, "by which we can at present determine the needs of a soil is to ask the question of the soil itself by growing a crop upon it with different kinds of fertilizers and noting the result. Such soil tests with fertilizers have in many cases given results of much immediate practical value for the locality in which they were undertaken." * * *

* * * Many materials containing the essential elements are practically worthless as sources of plant food because the form is not right. * * * All materials containing organic nitrogen are valuable in proportion to their rapidity of decay or change. * * * Thus organic nitrogen differs in availability not only according to the

kind of material which supplies it, but upon the treatment it receives. * * * The phosphoric acid in natural or untreated phosphates is insoluble in water and not readily available to plants; that is, the rate of availability depends largely upon the rapidity with which the substance rots or decays, and the rate of decay again depends upon the character of the substance with which the phosphate is associated. * * * Potash may exist in a number of forms, though chiefly as chlorids, or muriates, in which case the potash is combined with chlorin; and as sulphates in which the potash is combined with sulphuric acid. With potash, however, the form does not exert so great an influence upon availability as is the case with nitrogen and phosphoric acid. All forms are freely soluble in water, and are believed to be nearly if not quite equally available as food. The form of potash has, however, an important influence upon the quality of certain crops, due rather to the constituents with which the potash is associated than to the potash itself. * * * The character or form of the materials used must, therefore, be carefully considered in the use of manure. * * * All manufactured products or brands of fertilizers are made up of a mixture of the various kinds and forms of fertilizing materials just described, and the differences that exist in the brands of different manufacturers are due both to differences in the character and to the variations in proportions of the materials used to form the different brands; that is, while all manufacturers must go to the sources of supply indicated they may select either good or poor products and may vary the proportions of the different materials used.

The difference between a good brand of fertilizer and a poor one lies not so much in differences that may exist in the total amount of plant food contained in it as in the quality of the materials of which it is made.

Farmers' Bulletin 44, Commercial Fertilizers, Edward B. Voorhees, 1896.

The following extracts are from "Fertilizers," by Edward B. Voorhees, originally published in 1898, with a fourth edition in 1902:

Preface.—There is no question as to the desirability of the use of commercial fertilizers on most farms, though the methods now generally practiced are such as to indicate the very great need of a better understanding of what the functions of a fertilizer are, of the terms used to express their composition and value, of the kind that shall be used, and the time and method of application for the different crops under the varying conditions that exist. * * *

The author appreciates keenly his limitations, owing to the lack of definite knowledge on many vital points; yet it seems that at this time, when the investigations of the experiment stations are beginning to be regarded as important educational factors, and when these institutions are more than ever prepared to study the fundamental principles which underlie the various processes involved in plant nutrition, the practical man should have a clear understanding of what is now known, in order that he may be prepared to accept and use that better knowledge which will undoubtedly be provided for him in the near future.

Page 49.—It will be observed from the foregoing brief description of the chief sources of organic forms of nitrogen that a very wide variation occurs both in the composition or content of nitrogen in these products, and in the availability of their nitrogen, or rapidity with which, under similar conditions, it is given up to plants. The fact that a substance contains nitrogen in considerable amounts and in an organic form, then, is not a sufficient guide as to its usefulness.

Pages 54–57.—The practical point, and the one of prime importance to the farmer, is, then, to know how to estimate the relative value or usefulness of these different products, what is the rate of availability as compared with nitrate, and thus the relative advantage of purchasing the one or the other at the ruling market prices. Relative values, however, can not be assigned as yet, though careful studies of the problem have been made, chiefly by what are known as "vegetation tests"—that is, tests which show the actual amounts of nitrogen that plants can obtain from nitrogenous products of different kinds, when they are grown under known and controlled conditions. The results so far obtained, while only serving as a guide, indicate that when nitrate is rated at 100 per cent, blood and cotton-seed meal are about 70 per cent, dried and ground fish and hoof meal 65 per cent, bone and tankage 60 per cent, and leather and wool waste range from as low as 2 per cent to as high as 30 per cent. These figures furnish a fair basis for comparing the different materials, when used for the same purpose or under the same conditions. If, for example, the increased yield of oats due to the application of nitrate of soda is 1,000 pounds, the yield from blood and cotton-seed meal would be 700 pounds, the yield from dried ground fish and hoof meal would be 650 pounds, from bone and tankage 600 pounds, and from leather, ground horn, and wool waste from 20 to 300 pounds.

These figures alone are, however, not a sufficient guide as to the kinds to buy under all conditions, since the usefulness of the different forms are again dependent upon such other conditions as the kind of crop, the season, and the object of the application. * * *

In the making up of fertilizers, all of these considerations should be carefully balanced, and it is the practice on the part of many manufacturers to use a part of each of the three forms, so that a continuous feeding of the plant may be insured. Therefore, while the fact remains that fertilizers containing only the one form may not be the poorest, the chances are that those which contain all forms are likely to give more satisfactory results.

Pages 92–94.—It [potash] is, however, a very necessary constituent of fertilizers, being absolutely essential for those intended for light, sandy soils and for peaty meadow lands, as well as for certain potash-consuming crops, as potatoes, tobacco and roots, since these soils are very deficient in this element, and the plants mentioned require it in larger proportions than do others. * * *

Potash, as has already been stated in the discussion of phosphoric acid and nitrogen, exists in various forms, but it differs from the other elements in that its chemical form or combination seems to exert but relatively little influence upon the availability of the constituent. For example, it may be in a form of muriate or chlorid, of a sulphate or of a carbonate, and while there is a difference in the diffusibility of these different compounds—that is, a difference in the rate at which they will distribute in the soil before becoming fixed—there seems to be very little difference in the rate of the absorption of the potash by the plant. Nevertheless, the form of potash must be observed, because of the possible influence that the substances with which it combines may exert in reducing the marketable quality of the crop to which it is applied. This influence has been very distinctly observed, particularly in the growing of tobacco, sugar beets, and potatoes, and it has been shown that the potash in the form of a chlorid (or muriate) does exert a very deleterious effect, especially on tobacco.

Pages 129–130.—In the purchase of mixtures, consumers should demand that they be accompanied by a guarantee, because they are unable to determine the kind and proportion of the different materials entering into the mixture, either by its appearance, weight or smell. In mixing, too, an opportunity is afforded for disguising poor forms of the constitutents, particularly nitrogen. That is, in a mixture of nitrogenous materials, potash salts, and superphosphates, it would be a difficult matter to determine, by mere physical inspection, the proportion of the nitrogen which had been supplied in the form of horn meal and of blood, and the statement of the manufacturer on this point would be valuable in proportion to his reliability.

Page 149.—An analysis may show simply the total amount of the constituents. This is not a sufficient guide as to the value of the mixture, for while it is not possible to indicate absolutely by analysis whether the organic nitrogen, for example, is derived from blood (which is one of the best forms) or from horn meal (one of the poorer forms) it is possible to show whether the nitrogen is derived from nitrate or from ammonia, whether the phosphoric acid is derived from a superphosphate or a phosphate, and whether the potash present is in the form of a sulphate or of a muriate. A high-grade or a low-grade fertilizer, for example, may be distinctly indicated by the analysis, since it is of a high grade if the three forms of nitrogen are present, if the total phosphoric acid is chiefly soluble in water, and if the potash has been derived from a sulphate or from a muriate.

Page 152.—It is obvious, from what has been already pointed out, that the value of a fertilizer to the farmer depends not so much upon what is paid for it as upon the character of the material used to make it.

Page 175.—A ton of wheat, at $1 per bushel, will bring $33.33. Its sale removes from the farm 38 pounds of nitrogen, 19 of phosphoric acid, and 13 of potash. At prevailing prices for these constituents it would cost $6.50 to return them to the farm.

Pages 158–161.—It will be observed that the schedule gives the cost per pound of the different forms of nitrogen and of high-grade organic nitrogenous materials; of nitrogen and phosphoric acid in ground bone and tankage; of available phosphoric acid in superphosphates, and of actual potash in the potash salts, and is a useful guide also in showing that the nitrogen, phosphoric acid and potash contained in these materials can be purchased in ton lots for the prices mentioned. *The valuation of mixed fertilizers obtained by the use of this schedule are entirely commercial; they are not intended to indicate even a possible agricultural value.* * * *

Third. The chemical analysis does not show absolutely the sources of the materials, and thus it is difficult to place a true commercial value upon a mixture. This is especially true of organic nitrogen, since because it is impossible to separate the amounts that may be derived from different materials, a uniform value is placed upon the total nitrogen found, whether it is derived from the best forms, as dried blood and dried meat, or whether derived from horn meal, ground leather, or other low-grade forms of nitrogenous materials. This encourages the use of low-grade products by unscrupulous manufacturers, to the real detriment of the trade as a whole. * * *

Fourth. Any system of comparison of brands must leave a great deal to the judgment of the purchaser. He must interpret for himself whether he would rather that his phosphoric acid were derived from one source or another. * * *

Page 167.—The primary object in the use of a commercial fertilizer is to receive a profit from the increase in the yield of crops from the land to which it is applied; and this may be derived either from the immediate crop or from the larger yield of a number of crops. That the greatest immediate or prospective profit may be gained, a wide knowledge of conditions which have either a direct or indirect bearing upon the result is essential.

In fact, the controlling conditions surrounding the matter are so numerous and so various that it is impossible, with our present knowledge, to lay down positive rules for our guidance. At best, only suggestions can be offered.

Page 172.—It must be remembered, then, that only general rules apply in the use of fertilizers upon soils of different classes, and that they are modified by both the chemical composition and the mechanical condition of the soil. The best use of a fertilizer—that is, the greatest proportionate return of plant food in the crop, all things considered—is obtained from its application upon soils that possess "condition," or that are well cultivated or managed. Full returns can not be expected when they are applied upon soils that are too wet or too dry, too porous or too compact, or too coarse or too fine. It is important that even the best soils should be properly prepared, and it is infinitely more important that those which possess poor mechanical condition should be improved in this respect before large expenditures are made for fertilizers.

Pages 182-185.—The one [system of fertilization] which has perhaps received the most attention, doubtless largely because one of the first presented, and in a very attractive manner, is the system advocated by the celebrated French scientist, George Ville. This system, while not to be depended upon absolutely, suggests lines of practice which, under proper restrictions, may be of very great service. In brief, this method assumes that plants may be, so far as their fertilization is concerned, divided into three distinct groups. One group is specifically benefited by nitrogenous fertilization, the second by phosphatic, and the third by potassic. That is, in each class or group, one element more than any other rules or dominates the growth of that group, and hence each particular element should be applied in excess to the class of plants for which it is a dominant. In this system it is asserted that nitrogen is the dominant ingredient for wheat, rye, oats, barley, meadow grass, and beet crops. Phosphoric acid is the dominant fertilizer ingredient for turnips, Swedes, Indian corn (maize), sorghum and sugar cane; and potash is the dominant or ruling element for peas, beans, clover, vetches, flax and potatoes. It must be understood that this system advocates only single elements, for the others are quite as important up to a certain point, beyond which they do not exercise a controlling influence in the manures for the crops for the three classes. This special or dominating element is used in greater proportion than the others, and if soils are in a high state of cultivation, or have been manured with natural products, as stable manure, they may be used singly to force a maximum growth of the crop. * * *

Another system which has been urged, notably by German scientists, is based upon the fact that the mineral constituents, phosphoric acid and potash, form fixed compounds in the soil, and are, therefore, not likely to be leached out, provided the land is continuously cropped. They remain in the soil until used by growing plants, while the nitrogen, on the other hand, since it forms no fixed compounds and is perfectly soluble when in a form useful to plants, is liable to loss from leaching. Furthermore, the mineral elements are relatively cheap, while the nitrogen is relatively expensive, and thus that [sic] the economical use of this expensive element, nitrogen, is dependent to a large degree upon the abundance of the mineral elements in the soil. It is, therefore, advocated that for all crops and for all soils that are in a good state of cultivation, a reasonable excess of phosphoric acid and potash be applied, sufficient to more than satisfy the maximum needs of any crop, and that the nitrogen be applied in active forms, as nitrate of ammonia, and in such quantities and at such times as will insure the minimum loss of the element and the maximum development of the plant.

Page 186.—Another system of fertilization is based upon the theory that the different plants should be provided with the essential elements in the proportions in which they exist in the plants, as shown by chemical analysis. Different formulas are therefore recommended for each crop, the constituents of which are so proportionate as to meet its full needs. This method, if care is taken to supply an abundance of all of the necessary constituents, may result in a complete though perhaps not an economical feeding of the plant, since it assumes that a plant which contains a larger amount of one constituent than of another requires more of that constituent in the fertilizer than of the others. It does not take into consideration the fact that the plant which contains a larger amount of one element than another may possess a greater power of acquiring it than one which contains a smaller amount.

Pages 189-190.—The most expensive and irrational system of all, and one more commonly practiced than any other in general farming, may be termed the "hit or miss" system. If a "hit" is made, there is a profit, if a "miss," the loss is trifling. In this system no special thought is given to the character of the crop or its needs. If the farmer can afford it, he purchases a fertilizer, without regard to its composition, and applies it in very small amounts. If it happens to contain that element which is particularly needed for the plant to which it is applied, a profit is secured. In too many cases, however, the constituents added are already in abundance in the soil, or so little of the fertilizer is used as to preclude any profit.

Page 193.—The lacking element can not be fully determined, except by direct experiments by the farmer himself. That is, no general principle can be depended on as an absolute guide. He should learn whether his soil is deficient in any of the elements, and, if so, which one should be applied to the different crops in his rotation. A careful study along this line, too, will show whether it is fertilization that is required to meet seeming deficiencies, for it frequently happens that the needs of the soil are not so much for added plant food as for better management of the soil in other respects.

Pages 197-198.—The results of experiments which have been conducted with great care in a number of States show that where "extensive" methods are practiced certain elements need not be added in the fertilizers; that is, that the soil contains such an abundance of them that the plant is able to obtain a full supply, at least for a long time. For example, it has been shown that on the chief sugar-producing soils of Louisiana and Mississippi, and the cotton soils of Georgia and Texas, the addition of potash has been of less importance in the past than the other elements, and it frequently does not need to be included in the fertilizer, while phosphoric acid is always needed.

The results of field experiments on this plan in New Jersey, on reasonably good, loamy soils, indicate that phosphoric acid and potash are of much more importance in fertlilizers for corn than nitrogen, whereas upon sandy soils nitrogen and potash are of relatively more importance than phosphoric acid; that is, even where "extensive" practice is used there are conditions where one or more of the elements are not required in order to secure maximum crops, which eliminates the necessity for an immediate outlay for those constituents that are not lacking. Where experiments of this sort have not been carried out and the specific needs determined, *it becomes necessary to assume that all of the constituents are required*, and to apply the amounts and proportions of those which the general considerations of the soil, season, climate and crop would seem to demand.

As already pointed out, the methods of fertilization here suggested, though in many instances apparently positive, are not to be interpreted as absolute rules, but rather used as guides, based upon the best information that it has been possible to obtain, both as a result of scientific inquiry and of practical experience.

Pages 212-213.—The main point in this whole matter of fertilization is to understand that a fertilizer is a fertilizer because of the kind and form of plant food contained in it; and that its best action, other things being equal, is accomplished when the soil possesses good physical qualities, when the management is also good, and when systematic methods are planned and adopted. "Hit or miss" fertilization, even for these crops, may pay, and doubtless on the average does pay as well as some other things that farmers do, but does not pay as well as it might if better methods were used.

APPENDIX B.

A SUMMARY OF THE GUARANTEED ANALYSES OF THE FERTILIZERS SOLD IN SEVERAL STATES.

In this review or analysis of the figures showing the composition of the brands of fertilizers sold in the several States, the guaranteed minimum compositions only are used, as these are usually expressed in whole numbers or even per cents and as they in most cases agree very well with the amounts found by analyses. The figures for nitrogen occurring in some of the reports have been calculated in ammonia (NH_3) for purposes of comparison, and in a few cases small fractions of a per cent have been neglected and the result stated in the nearest whole number. None of the remarks or observations made in connection with the figures have been quoted from the official publications.

CONNECTICUT.[a]

During 1907 thirty-six individuals or firms have entered for sale in this State 279 brands of fertilizers, viz:

Special manures for particular crops	126
Other nitrogenous superphosphates	98
Bone manures and "bone and potash"	23
Fish, tankage, castor pomace, and chemicals	32
Total	279

Classification of the fertilizers analyzed.

1. Containing nitrogen as the chief active ingredient:
    Nitrate of soda.
    Sulphate of ammonia.
    Dried blood.
    Cotton-seed meal.
    Castor pomace.
    Linseed meal.
2. Containing phosphoric acid as the chief active ingredient
    Dissolved phosphate rock.
    Basic slag.
    Precipitated bone.
3. Containing potash as the chief active ingredient:
    Carbonate of potash.
    High-grade sulphate of potash.
    Double sulphate of potash and magnesia.
    Muriate of potash.
    Kainit.
4. Containing nitrogen and phosphoric acid:
    Bone manures.
    Slaughter-house tankage.
    Dry-ground fish.
5. Mixed fertilizers:
    Nitrogenous superphosphates.
    Special manures.
    Home mixtures.
6. Miscellaneous fertilizers and manures:
    "Vegetable potash."
    Cotton-hull ashes.
    Wood ashes.
    Lime and lime-kiln ashes.
    Others, miscellaneous.

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[a] Biennial Report, Conn. Agr. Expt. Sta., 1907-8.

Trade values of fertilizer elements for 1907.

	Cents per pound.
Nitrogen in nitrates	18½
ammonia salts	17½
Organic nitrogen in dry and fine ground fish, meat, and blood, and in mixed fertilizers	20½
in fine bone and tankage	20½
in coarse bone and tankage	15
Phosphoric acid, water-soluble	5
citrate-soluble	4½
of fine ground bone and tankage	4
of coarse bone and tankage	3
of cotton-seed meal, castor pomace, and ashes	4
of mixed fertilizers, if insoluble in ammonium citrate	2
Potash as high-grade sulphate in forms free from muriate (or chlorids)	5
as muriate	4¼

Composition of the nitrogenous superphosphates summarized.

Number of brands.	Phosphoric acid.	Number of brands.	Ammonia.	Number of brands.	Potash.
	Per cent.		*Per cent.*		*Per cent.*
2	10	2	8	9	10
17	9	2	7	1	8.8
34	8	1	6	4	8
14	7	9	5	13	7
20	6	2	4.5	13	6
6	5	17	4	4	5
7	4	2	3.5	2	4.5
		34	3	16	4
		8	2.5	1	3.8
		6	2	2	3.5
		2	1.5	6	3
		13	1	1	2.5
				24	2
				2	1.5
				2	1

Composition of the nitrogenous superphosphates.

Number of brands.	Phosphoric acid.	Ammonia.	Potash.	Number of brands.	Phosphoric acid.	Ammonia.	Potash.
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*
1	10	3	2.5	1	7	5	6
1	10	2.5	3.5	1	7	5	5
1	9	4	6	1	7.5	4.5	10
2	9	3.5	4.5	1	7.5	4.5	8.8
2	9	3	8	2	7	4	7
1	9	3	4	1	7	1	2
7	9	3	2	1	7	1	1
1	9	2.5	2	1	6.5	8	2
1	9	1.5	2	2	6	7	5
2	9	1	2	1	6	6	6
1	8	5	7	2	6	4	10
5	8	4	7	1	6	4	7
1	8	4	6	3	6	4	6
4	8	3	6	3	6	3	10
6	8	3	4	1	6	3	8
2	8	2.5	3	1	6	3	7
1	8	2.5	1.5	2	6	3	2
1	8	2	3	2	6	2.5	2
3	8	2	2	1	6	1.5	3
1	8	1	5	1	5	4	4
3	8	1	4	2	5	3	3
1	8	1	3.5	1	5	3	10
3	8	1	2	1	5	2	4
1	8	1	1.5	1	5	1	2
1	8	1	1	1	4	5	6
1	7	8	10	1	4	4	3.8
1	7	5	10	3	4	3	4
1	7	5	8	1	4	2.5	6
3	7	5	7	1	4	2	4

Composition of special brands of fertilizers for special crops.

FOR TOBACCO.

Number of brands.	Phosphoric acid.	Ammonia.	Potash.	Number of brands.	Phosphoric acid.	Ammonia.	Potash.
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*
1	9	3	2	1	6	5	1
1	8	4	5	2	6	4	6
2	8	4	4	1	6	3	10
1	8	3	3	1	5	7	10
1	8	2.5	6	2	5	5.5	5
2	8	2.5	3	1	5	3.5	7
1	8	2	4	1	4	7	10
1	7	6	10	1	4	6	6
2	7	5	6	2	4	5	5
1	7	4	8	1	4	4.5	3
2	6	7.25	9	4	3	5.5	5
2	6	6	11	1	3	5	5

FOR POTATOES.

1	9	2	5	1	7	4	7
1	9	2	2	1	7	4	6
1	8	4.5	6	1	7	2	6
4	8	4	7	2	7	2	4
1	8	3.25	7	1	7	1.5	2
2	8	3	7	1	7	1	3
3	8	3	6	3	6	4	10
1	8	3	5	2	6	4	6
1	8	3	4	4	6	3	5
3	8	2.5	6	1	6	2.5	4
4	8	2.5	3	1	6	2	4
4	8	2	10	1	5	2	10
1	8	2	4	1	5	2	6
1	8	2	3	1	4	4	8
1	7	6	5	1	4	1	8
1	7	4.5	8				

FOR CORN, GRAIN, AND GRASS.

1	10	4	7	1	7	2	2
2	9	3	2	1	7	1.5	2
1	9	2	5	1	6	5	5
1	8	6	8	1	6	4.75	2
1	8	3	6	1	6	4.25	7
1	8	3	4	1	6	4	6
4	8	2.5	1	1	6	2.5	12
1	8	2	5	1	6	2	3
1	8	2	3	1	5	6	2
3	8	2	2	1	4	6	6
2	7	7.5	7	1	4	6	2
1	7	5	7	1	4	3.5	5
1	7	5	6	1	3.9	10.25	8

MASSACHUSETTS.

The following explanatory statement is taken from the official bulletin giving the results of the fertilizer inspection for the season of 1907:[a]

The organic nitrogen in the mixed goods is valued as coming from the best grade of raw materials and is counted at 20½ cents per pound. This method of valuing the organic nitrogen in mixed fertilizers will of course give a too high value on those goods in which the organic nitrogen has been derived from low-grade materials which possess slowly available nitrogen. This seems to be the only course, however, at present, as the ordinary methods of analysis will not discriminate between the available and inert forms of organic nitrogen.

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[a] Inspection of Commercial Fertilizers, Mass. Agr. Expt. Sta., Bul. No. 119, December, 1907.

Soluble phosphoric acid is valued at 5 cents per pound, citrate soluble or reverted phosphoric acid at 4½ cents, and the phosphoric acid which is insoluble in ammonium citrate (usually termed "insoluble phosphoric acid") at 2 cents per pound. Potash is valued according to the form in which it is found present in the fertilizer. Whenever a potash test is reported in the tables without comment or footnote, it will be understood that sufficient chlorine was present to unite with all of the potash. Every brand of complete fertilizer is tested for chlorides, and if sufficient chlorine is found to unite with all of the potash it is taken for granted that the potash exists in the form of muriate and is counted as worth 4½ cents per pound. The presence of chlorine does not necessarily prove that it is in combination with the potash, but its presence in a fertilizer supposed and advertised to be free from chlorides or where the potash is said to be present as sulphate or carbonate, is just as objectionable as though it was actually in combination with the potash. Whenever the potash is guaranteed to be present as sulphate and the analysis shows the presence of chlorine, a footnote has been used to indicate how much is present in each form. Wherever only very small quantities of chlorides are present the potash has been reported as sulphate. Potash in form of sulphate has been valued at 5 cents per pound.

Whenever the potash is guaranteed as carbonate a test has been made for chlorides and sulphates, and a footnote indicates how much potash is present in each form. Potash in form of carbonate has been valued at 8 cents per pound.

Whenever it was known that potash had been derived wholly or in part from organic sources, in mixed fertilizers, a total potash test has been made which will be found reported in a footnote. No attempt has been made to place a valuation on that portion of the potash which is insoluble in water. It no doubt has a commercial value, but as we have no basis for establishing its worth, the results have simply been reported without comment. It should not be understood that all of the potash in vegetable organic compounds is insoluble in water. As a matter of fact, about 80 per cent of the potash in cotton-seed meal is recovered in a water soluble potash test. * * *

The agricultural value of a fertilizer represents its crop-producing power, which is far from constant on all soils.

The beneficial effect of any fertilizer on a particular soil depends on whether the fertilizer in question contains those elements of plant food in suitable quantity and quality in which the soil is deficient. In other words the supply of plant food in soils varies widely and every user of commercial fertilizers must select his fertilizer according to the conditions of his soil and the requirements of the crop which he wishes to raise. We are often asked which is the best mixed fertilizer to use. The consumer can better answer this question for himself by a study of his soil conditions and crop requirements. A general statement may be made, however, to the effect that, all conditions being equal, the consumer should select those fertilizers which give the greatest amount of plant food in suitable and available forms for the least money. A study of the tables of analyses should furnish reliable data in making fertilizer selections. The tables show the quality and quantity of the various essential elements of plant good [food] with the possible exception of organic nitrogen. Prescribed methods of analysis do not include a wholly reliable means of determining the availability of organic nitrogen, and in all valuations, in case of the mixed goods, it is assumed that the organic nitrogen is present in the best forms.

The high-grade fertilizers will, as a general rule, be the most economical ones to buy, and the low-grade fertilizers will, ordinarily, be the most expensive ones. In the manufacture of the best goods only high-grade raw materials and chemicals can be used as the formula has to be made up of compounds whose united composition will furnish the desired quantity and quality of plant food and whose combined weight must not exceed 2,000 pounds. On the other hand, in the manufacture of very low-grade fertilizers the necessary compounds to supply the percentage of nitrogen, phosphoric acid and potash which is guaranteed might be supplied in 1,200 to 1,500 pounds of material of good quality and the remainder, to make up the ton weight, will be a filler of some sort which oftentimes has no fertilizing value whatever. Besides this, the consumer is obliged to pay freight and cartage on low-valued or worthless material. Many low-grade goods contain a high percentage of phosphoric acid. It should be borne in mind that phosphoric acid is the cheapest of the essential elements of plant food, and that some of the low-grade mixed goods contain an excess of this material. Cheap or low-grade fertilizers are sometimes made up of crude stock having a comparatively low commercial and agricultural value.

There were 317 brands of fertilizers entered for sale in the State. Of these, there are 249 brands of complete fertilizers with manufacturers' guarantees of the percentage of phosphoric acid, ammonia (nitrogen), and potash, 155 of them being special brands for special crops. An analysis of these figures for the nitrogenous superphosphates is given herewith:

Composition of the nitrogenous superphosphates summarized.

Number of brands.	Phosphoric acid.	Number of brands.	Ammonia.	Number of brands.	Potash.
	Per cent.		*Per cent.*		*Per cent.*
1	11	1	18	2	12
3	10	1	10.25	1	11
22	9	1	8	30	10
2	8.5	1	7.75	1	9.5
105	8	1	7	1	8.75
40	7	1	6.5	1	8.5
2	6.5	9	6	9	8
40	6	2	5.75	2	7.5
15	5	6	5.5	29	7
1	4.5	16	5	2	6.5
13	4	3	4.75	26	6
1	3.5	7	4.5	2	5.5
2	3	7	4.25	22	5
1	2.9	45	4	2	4.75
1	.75	9	3.5	3	4.5
		2	3.25	24	4
		43	3	1	3.75
		30	2.5	1	3.5
		1	2.25	24	3
		32	2	5	2.5
		1	1.75	2	2.25
		9	1.5	46	2
		7	1.25	8	1.5
		14	1	4	1
				1	.25

Composition of the nitrogenous superphosphates.

Number of brands.	Phosphoric acid.	Ammonia.	Potash.	Number of brands.	Phosphoric acid.	Ammonia.	Potash.
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*
1	11	3	10	1	8	3	6
2	10	4	7	7	8	3	4
1	10	3	2.5	2	8	3	5
1	9	4.25	2	1	8	3	3
2	9	3.5	4.75	3	8	2.5	6
1	9	3.5	4.5	1	8	2.5	5
1	9	3	2.5	11	8	2.5	3
9	9	3	2	7	8	2.5	1.5
1	9	2.5	2.25	2	8	2	10
1	9	2.5	5	1	8	2	5
1	9	2.5	3	1	8	2	4
1	9	2.25	2.25	5	8	2	3
2	9	2	2	5	8	2	2
1	9	2	4	1	8	1.75	2
1	9	1.5	2	2	8	1.5	10
1	8.5	1.5	2.5	3	8	1.5	2
1	8.5	1	1.5	1	8	1.25	10
1	8	6.5	4	1	8	1.25	3.5
1	8	6	8	4	8	1.25	2
1	8	5.5	8	1	8	1	5
1	8	5.5	5	3	8	1	4
1	8	5	10	1	8	1	3
1	8	5	7	2	8	1	2
1	8	4.5	6	1	7	8	7.5
2	8	4.25	7	1	7	7	8
1	8	4.25	5	1	7	6	10
13	8	4	7	1	7	6	5
1	8	4	6	1	7	5.5	12
2	8	4	5	4	7	5	7
2	8	4	4	3	7	5	6
1	8	4	3	2	7	5	5
1	8	3.5	6.5	1	7	4.5	10
1	8	3.5	6	1	7	4.5	8.5
1	8	3.5	4	2	7	4.25	10
1	8	3.5	10	1	7	4.25	8.75
1	8	3.5	8	2	7	4	10
1	8	3.25	7	1	7	4	9.5

Composition of the nitrogenous superphosphates—Continued.

Number of brands.	Phosphoric acid.	Ammonia.	Potash.	Number of brands.	Phosphoric acid.	Ammonia.	Potash.
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*
1	7	4	7	1	6	1	2
2	7	4	6	1	5	18	3
1	7	3	8	1	5	6	5
1	7	3	5	1	5	6	2.5
1	7	3	4	1	5	5.75	7
2	7	2	6	1	5	5.75	2.5
2	7	2	4	1	5	5	5
2	7	2	2	1	5	4.75	2
2	7	1.5	2	1	5	4	7
1	7	1.25	2	1	5	3.5	5
3	7	1	1	1	5	3	3
1	6.5	4.75	4.5	1	5	3	2
1	6.5	2.5	12	1	5	2	10
1	6	6	11	2	5	2	2
1	6	6	6	1	5	1	10
1	6	5	6	1	4.5	2	2
1	6	5	5	1	4	10.25	8
1	6	5	4	1	4	7	10
1	6	5	1	1	4	6	6
1	6	4.5	7.5	1	4	6	2
2	6	4.5	7	1	4	4.75	5
7	6	4	10	1	4	4	8
5	6	4	6	1	4	4	7
1	6	3.25	10	1	4	4	5
5	6	3	10	1	4	4	3.75
1	6	3	8	2	4	3	4
2	6	3	5	1	4	2.5	2
1	6	3	4	1	4	1	8
1	6	2.5	4.5	1	3.5	4	3
2	6	2.5	2	2	3	5.5	5.5
1	6	2	4	1	2.9	7.75	6.5
1	6	2	3	1	.75	5.5	.25
3	6	2	2				

Composition of special brands of fertilizers for special crops.

FOR TOBACCO.

Number of brands.	Phosphoric acid.	Ammonia.	Potash.	Number of brands.	Phosphoric acid.	Ammonia.	Potash.
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*
1	9	2	4	1	7	6	10
1	9	3	2.5	1	7	5.5	12
1	8	2	4	1	7	5	6
2	8	2.5	3	1	7	4.25	8.75
1	8	2.5	6	1	6	6	11
1	8	5	10	1	6	5	1
1	8	4	7.4	1	5	4	7
1	8	4	5.4	1	4	7	10
1	8	4	5	1	4	5	5
1	8	3	3	2	3	5.5	5.5

FOR POTATOES.

1	9	3.5	4.75	1	7	6	5
1	9	2.5	5	1	7	4.5	8.5
1	9	2	2	1	7	4	7
1	8.5	1.5	2.5	2	7	4	6
1	8	4.5	6	1	7	3	8
4	8	4	7	1	7	3	4
1	8	3.5	10	2	7	2	6
1	8	3.5	6.5	2	7	2	4
1	8	3	6	8	6	4	10
1	8	3	5	1	6	4	6
1	8	2.75	5	1	6	3	10
2	8	2.5	6	2	6	3	5
1	8	2.5	5	1	6	2.5	4.5
8	8	2.5	3	1	6	2	4
2	8	2	10	1	4	4	8
1	8	2	8	1	4	1	8
1	8	1.5	10				

Composition of special brands of fertilizers for special crops—Continued.

FOR MARKET-GARDEN CROPS.

Number of brands.	Phosphoric acid.	Ammonia.	Potash.	Number of brands.	Phosphoric acid.	Ammonia.	Potash.
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*
1	9	4.25	2	1	7	4.25	10
1	8	5.5	8	1	6.5	5	4.5
8	8	4	7	1	6	6	6
1	8	5	6	1	6	5	6
1	8	4	4	2	6	4.5	7
1	8	3.5	6	2	6	3	10
1	8	3.25	7	1	5	6	5
1	8	3	6	1	5	3.5	5
1	8	2	5	1	5	2	10
2	8	2	2	1	4	4	7
1	8	1	10	1	4	4	5
1	7	5	6	1	4	2.5	2
1	7	5	5	1	2.9	8	6.5

FOR CORN, GRAIN, AND GRASS.

2	10	4	7	1	7	4	10
2	9	3	2	1	7	2	2
1	9	2.5	3	2	7	1.5	2
1	8	6	8	1	7	1	1
1	8	5.5	5	1	6.6	2.5	12
1	8	4	3	1	6	5	5
1	8	3.25	8	1	6	4.5	7
1	8	3	6	1	6	3	10
3	8	3	4	1	6	3	8
4	8	2.5	1.5	1	6	2	3
4	8	2	3	1	5	5.5	7
1	8	2	2	2	5	6	2.5
1	8	1.5	2	1	5	5	5
1	7	8	7.5	1	5	5	2
1	7	7	8	1	4	6	2
1	7	5	7	1	4	6	6
1	7	5	6	1	3.9	10.25	8

MAINE.[a]

The following explanatory statement is taken from pages 85–89 of the official bulletin giving the results of the fertilizer inspection by the Maine station for 1908:

> The law regulating the sale of commercial fertilizers in this State calls for two bulletins each year. The first of these contains the analyses of the samples received from the manufacturer, guaranteed to represent, within reasonable limits, the goods to be placed upon the market later. The second bulletin contains the analyses of the samples collected in the open market by a representative of the station.
>
> In the tables which follow the discussion there are given the results of the analyses of the manufacturers' samples of licensed brands. The tables include all the brands which have been licensed to February 10, 1908. Dealers are cautioned against handling brands not given in this list without first writing the station. * * *
>
> To produce profitable crops and at the same time to maintain and even to increase the productive capacity of the soil may rightly be termed "good farming." Many farmers are able to do this, and the knowledge of how to do it has been largely acquired through years of experience, during which the character of the soil, its adaptability for crops, and the methods of its management and manuring have been made the subjects of careful study, without, however, any definite and accurate knowledge concerning manures and their functions in relation to soils and crops. * * *
>
> Soils vary greatly in their capabilities of supplying food to crops. Different ingredients are deficient in different soils. The way to learn what materials are proper in a given case is by observation and experiment. The rational method for determining what ingredients of plant-food a soil fails to furnish in abundance, and how these lacking materials can be most economically supplied, is to put the question to the soil with different fertilizing materials and get the reply in the crops produced. * * *

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[a] Maine Agr. Expt. Sta., Bull. 153, March, 1908.

* * * It is good farming to make the most of the natural resources of the soil and of the manures produced on the farm and to depend upon artificial fertilizers only to furnish what more is needed. It is not good economy to pay high prices for material which the soil may itself yield, but it is good economy to supply the lacking ones in the cheapest way. The rule in the purchase of costly commercial fertilizers should be to select those that supply, in the best forms and at the lowest cost, the plant-food which the crop needs and the soil fails to furnish.

Plants differ widely with respect to their capacities for gathering their food from soil and air; hence the proper fertilizer in a given case depends upon the crop as well as upon the soil. The fertility of the soil would remain practically unchanged if all the ingredients removed in the various farm products were restored to the land. * * *

The term "form" as applied to a fertilizing constituent has reference to its combination or association with other constituents which may be useful, though not necessarily so. The form of the constituent, too, has an important bearing upon its availability, and hence upon its usefulness as plant food. Many materials containing the essential elements are practically worthless as sources of plant food because the form is not right; the plants are unable to extract them from their combinations; they are "unavailable." In many of these materials the forms may be changed by proper treatment, in which case they become valuable not because the element itself is changed, but because it then exists in such form as readily to feed the plant. * * *

The agricultural value of any fertilizing constituent is measured by the value of the increase of the crop produced by its use, and is, of course, a variable factor, depending upon the availability of the constituent and the value of the crop produced. The form of the materials used must be carefully considered in the use of manures. Slow-acting materials can not be expected to give profitable returns upon quick-growing crops, nor expensive materials profitable returns when used for crops of relatively low value.

The agricultural value is distinct from what is termed "commercial value," or cost in market. This last is determined by market and trade conditions, as cost of production of the crude materials, methods of manipulation required, etc. Since there is no strict relation between agricultural and commercial or market value, it may happen that an element in its most available form, and under ordinary conditions of high agricultural value, costs less in market than the same element in less available forms and of a lower agricultural value. The commercial value has reference to the material as an article of commerce; hence commercial ratings of various fertilizers have reference to their relative cost and are used largely as a means by which the different materials may be compared.

There were 209 brands of fertilizers placed upon the market, of which 186 brands were complete fertilizers, containing phosphoric acid, ammonia (nitrogen), and potash, which we will call nitrogenous superphosphates. Of these, 63 brands were designated as special brands for potatoes, and 35 brands for corn, grass, and grain. An analysis of the guaranteed figures shows the following composition of the brands of fertilizers sold in the State of Maine:

Composition of the nitrogenous superphosphates summarized.

Number of brands.	Phosphoric acid.	Number of brands.	Ammonia.	Number of brands.	Potash.
	Per cent.		*Per cent.*		*Per cent.*
1	10	1	7	1	12
10	9	1	6	43	10
99	8	9	5	6	8
30	7	1	4.75	23	7
38	6	6	4.50	12	6
4	5	22	4	8	5
3	4	2	3.5	15	4
1	3	51	3	23	3
		29	2.5	2	2.5
		24	2	32	2
		6	1.5	13	1.5
		11	1.25	8	1
		22	1		
		1	.5		

Composition of the nitrogenous superphosphates.

Number of brands.	Phosphoric acid.	Ammonia.	Potash.	Number of brands.	Phosphoric acid.	Ammonia.	Potash.
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*
1	10	4	7	3	7	5	7
1	9	4	6	6	7	4.5	10
5	9	3	2	3	7	3	8
2	9	2	2	1	7	3	5
1	9	2	12	2	7	2	4
1	9	1.5	2	1	7	2	3
2	8	5	7	2	7	1.5	2
1	8	4	10	8	7	1	1
1	8	4	6	1	7.5	1	3
1	8	3.5	4	1	6	5	5
17	8	3	7	17	6	4	10
4	8	3	6	1	6	3.5	10
6	8	3	4	10	6	3	10
4	8	2.5	6	4	6	3	5
14	8	2.5	3	1	6	2	2
11	8	2.5	1.5	1	6	1.5	3
3	8	2	10	1	6	1	6
2	8	2	5	1	6	1	4
1	8	2	4	1	6	1	2
5	8	2	3	1	5	4.75	2
6	8	2	2	1	5	4	10
11	8	1.25	2	1	5	3	10
4	8	1	4	1	5	1	10
1	8	1	3	1	4	6	6
2	8	1	2	1	4	1	8
2	8.5	1.5	2.5	1	4	1	2
2	7	5	10	1	3	7	8
1	7	5	8				

Composition of special brands of fertilizers for special crops.

FOR POTATOES.

Number of brands.	Phosphoric acid.	Ammonia.	Potash.	Number of brands.	Phosphoric acid.	Ammonia.	Potash.
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*
1	9	2	12	1	7.5	1	3
1	8.5	1.5	2.5	1	7	5	10
1	8	4	10	3	7	4.5	10
6	8	4	7	1	7	3	8
4	8	3	6	1	7	3	5
1	8	3	4	1	7	2.5	8
3	8	2.5	6	2	7	2	4
1	8	2.5	5	12	6	4	10
11	8	2.5	4	5	6	3	10
2	8	2	10	3	6	3	5
1	8	2	4	1	6	1.25	4
1	8	2	3	1	6	1	6
1	8	2	2	1	4	1	8
1	8	1	4				

FOR CORN, GRAIN, AND GRASS.

1	10	4	7	2	8	1.25	2
1	9	3	2	1	7	5	7
1	8.5	1.5	2.5	1	7	1.5	2
1	8.5	1	1.5	3	7	1	1
1	8	5	7	3	6	3	10
3	8	4	7	1	6	3	5
1	8	2.5	6	1	6	1.5	3
5	8	2.5	1.5	1	5	5	2
3	8	2	3	1	4	6	6
4	8	2	2				

NORTH CAROLINA.

There were 1,805 brands of fertilizers registered for sale in North Carolina in the spring season of 1908. The following explanatory matter or advice as to making suitable selections from this great mass of material is taken from the official bulletin giving the results of the inspection,[a] and is probably about all that can be safely and positively stated in a general way with our present knowledge of fertilizers, soil, and crops, but it is in strange contrast with the assurance and knowledge implied in the names and compositions of the brands put out by the different manufacturers:

> The analyses presented in this bulletin are of samples collected by the fertilizer inspectors of the department, under the direction of the Commissioner of Agriculture, during the spring months of 1908. They should receive the careful study of every farmer in the State who uses fertilizers, as by comparing the analyses in the bulletin with the claims made for the fertilizers actually used, the farmer can know by, or before, the time fertilizers are put in the ground whether or not they contain the fertilizing constitutents in the amounts they were claimed to be present. * * *
>
> *Water-soluble ammonia.*—The main materials furnishing ammonia in fertilizers are nitrate of soda, sulphate of ammonia, cotton-seed meal, dried blood, tankage, and fish scrap. The first two of these (nitrate of soda and sulphate of ammonia) are easily soluble in water and become well distributed in the soil where plant roots can get at them. They are, especially the nitrate of soda, ready to be taken up by plants, and are therefore quick-acting forms of ammonia. It is mainly the ammonia from nitrate of soda and sulphate of ammonia that will be designated under the heading of water-soluble ammonia.
>
> *Organic ammonia.*—The ammonia in cotton-seed meal, dried blood, tankage, fish scrap, etc., is included under this heading. These materials are insoluble in water, and before they can feed plants they must decay and have their ammonia changed, by the aid of the bacteria of the soil, to nitrates, similar to nitrate of soda.
>
> They are valuable then as plant food in proportion to their content of ammonia, and the rapidity with which they decay in the soil, or rather the rate of decay, will determine the quickness of their action as fertilizers. With short season, quick-growing crops, quickness of action is an important consideration, but with crops occupying the land during the greater portion or all of the growing season it is better to have a fertilizer that will become available more slowly, so as to feed the plant till maturity. Cotton-seed meal and dried blood decompose fairly rapidly, but will last the greater portion, if not all, of the growing season in this State. While cotton seed and tankage will last longer than meal and blood, none of these act so quickly or give out so soon as nitrate of soda and sulphate of ammonia.
>
> *Total ammonia* is made up of the water-soluble and organic; it is the sum of these two.
>
> The farmer should suit, as far as possible, the kind of ammonia to his different crops, and a study of the forms of ammonia as given in the tables of analyses will help him to do this.

The general character of the brands is as follows:

		Brands.
Material valued only for phosphate supplied:		
Acid phosphate, slag, and raw rock		236
Material valued only for nitrogen supplied:		
Nitrate of soda	45	
Sulphate of ammonia	11	
Fish scrap	6	
Dried blood	8	
		70
Material valued only for potash supplied:		
Kainit	61	
Muriate of potash	37	
Sulphate of potash	24	
Mixed salts	1	
		123
Material valued only for phosphoric acid and nitrogen supplied:		
Bone and tankage		33

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[a] Analyses of Fertilizers, spring season 1908, the Bulletin of the North Carolina Department of Agriculture, vol. 29, No. 4, April, 1908.

Mixed fertilizers:	Brands.
Containing nitrogen and potash	5
Containing phosphoric acid and potash	246
Complete fertilizers, containing phosphoric acid, nitrogen, and potash	1,092
	1,805

Of the 1,092 brands of complete fertilizers, 504 are special brands for special crops, as follows:

3 brands for fruit.
176 brands for tobacco.
11 brands for peanuts.
38 brands for corn, grain, and grass.
94 brands for cotton.
68 brands for potatoes.
114 brands for truck.

Nearly half of the complete fertilizers, or nearly a third of the whole number of brands offered for sale, purport to be special brands for special crops.

The 246 fertilizers containing only phosphoric acid and potash have the following composition:

Composition of fertilizers analyzed.

Number of brands.	Phosphoric acid.	Potash.	Number of brands.	Phosphoric acid.	Potash.
	Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
1	21	37	4	10	6
1	13	4	12	10	5
2	12	3	42	10	4
3	12	6	13	10	3
7	12	5	81	10	2
7	12	4	1	9	4
8	12	3	5	8	5
2	12	1	38	8	4
4	11	5	1	8	2
6	11	2	3	7	5
5	11	1			

The following special brands for special crops are contained in the phosphoric-acid and potash fertilizers:

Composition of special phosphoric-acid and potash fertilizers for special crops.

For peanuts.			For potatoes.			For corn, grain, and grass.		
Number of brands.	Phosphoric acid.	Potash.	Number of brands.	Phosphoric acid.	Potash.	Number of brands.	Phosphoric acid.	Potash.
	Per cent.	*Per cent.*		*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*
1	11	2	1	10	6	1	12	5
1	10	2	1	10	2	3	12	4
3	8	4				1	10	6
3	7	5				5	10	4
						5	10	3
						11	10	2
						12	8	4

Composition of the 1,092 brands of complete fertilizers summarized.

Number of brands.	Phosphoric acid.	Number of brands.	Ammonia.	Number of brands.	Potash.
	Per cent.		*Per cent.*		*Per cent.*
1	25	1	27.5	17	10
1	23	1	11	2	9
1	17	20	10	17	8
1	17	3	7.5	59	7
2	15	44	7	37	6
2	13	1	6.75	98	5
1	11	15	6	1	4.5
48	10	2	5.5	117	4
26	8.5	76	5	282	3
662	8	2	4.75	2	2.75
81	7	7	4.5	42	2.5
79	6	1	4.25	2	2.25
26	5	91	4	364	2
9	4	11	3.5	7	1.5
3	3	2	3.25	44	1
3	2	246	3		
1	1	42	2.75		
		132	2.5		
		22	2.25		
		329	2		
		41	1		

Composition of the 1,092 brands of complete fertilizers.

Number of brands.	Phosphoric acid.	Ammonia.	Potash.	Number of brands.	Phosphoric acid.	Ammonia.	Potash.
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*
1	25	4	6	3	8	2.5	4
1	23	2	2	55	8	2.5	3
1	17	3.5	3	5	8	2.5	2.5
1	16	2	2.5	33	8	2.5	2
1	15	4.25	3	5	8	2.5	1.5
1	15	3	5	1	8	2.5	1
2	12	2	2	1	8	2.25	2.5
1	11	3	4	2	8	2.25	2.25
3	10	4	5	3	8	2	10
2	10	4	4	3	8	2	6
2	10	3	10	5	8	2	5
6	10	3	3	8	8	2	4
1	10	3	2	11	8	2	3
1	10	2	5	210	8	2	2
1	10	2	4	1	8	2	1
1	10	2	3	9	8	1	4
15	10	2	2	5	8	1	3
1	10	1	5	1	7	8	5
5	10	1	3	1	7	7.5	10
9	10	1	1	16	7	7	7
1	9	27.5	2	1	7	7	5
1	9	6.75	2	1	7	7	4
1	9	5	7	1	7	6	6
1	9	5	3	2	7	6	5
1	9	4	7	10	7	5	8
1	9	4	5	8	7	5	7
1	9	4	2.5	1	7	5	6
1	9	3.5	9	18	7	5	5
3	9	3.5	5	1	7	5	4
2	9	3	6	1	7	4.5	6
1	9	3	5	1	7	4	8
1	9	3	4	1	7	4	7
13	9	3	3	1	7	4	5
4	9	3	2	5	7	4	4
1	9	2.25	1	1	7	3.5	7
22	9	2.75	2	1	7	3.25	2.75
5	9	2.5	5	1	7	3	10
4	9	2.5	3	1	7	3	7
6	9	2.5	2	1	7	3	5
4	9	2.5	1	1	7	3	4
9	9	2.25	4	2	7	3	3
1	9	2.25	3	1	7	3	2
8	9	2.25	1	1	7	2	5
1	9	2	4	1	7	2	4
2	8	2.75	2.5	5	9	2	3
6	8	2.75	2	18	9	2	2
2	8	2.5	6	17	9	2	1
1	8	2.5	5	4	9	1	3

Composition of the 1,092 brands of complete fertilizers—Continued.

Number of brands.	Phosphoric acid.	Ammonia.	Potash.	Number of brands.	Phosphoric acid.	Ammonia.	Potash.
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*
8	9	1	2	20	6	7	5
1	8.5	3	4	1	6	6	8
1	8.5	3	2.5	2	6	6	7
1	8.5	2.75	2	5	6	6	6
4	8.5	2.5	2.5	1	6	5.5	10
3	8.5	2.5	1	15	6	5	7
15	8.5	2	2	2	6	5	6
1	8.5	2	1.5	3	6	5	5
1	8	6	6	1	6	4.5	4
1	8	6	5	1	6	4	8
5	8	5	7	6	6	4	4
7	8	5	5	1	6	3	6
1	8	5	3	5	6	3	3
1	8	5	2	1	6	3	2.5
1	8	4.75	4	1	6	2.5	3
1	8	4.75	2.75	2	6	2	6
4	8	4.5	7	1	6	2	5
1	8	4.5	4	1	6	2	4.5
2	8	4	7	5	5	10	3
4	8	4	6	7	5	10	2.5
3	8	4	5	2	5	10	2
40	8	4	4	1	5	8	3
6	8	4	3	2	5	7	5
1	8	4	2.5	1	5	6	9
1	8	4	2	1	5	6	7
1	8	3.5	7.5	2	5	5	5
2	8	3.5	5	1	5	4	6
1	8	3.5	4	1	5	3	6
1	8	3.5	3	1	5	2	10
1	8	3.25	2	1	5	2	6
6	8	3	10	1	5	2	5
1	8	3	6	1	4	7.5	2.5
7	8	3	5	1	4	4	8
15	8	3	4	3	4	4	6
146	8	3	3	2	4	4	4
8	8	3	2.5	1	4	3	6
11	8	3	2	1	4	3	5
1	8	2.75	10	2	3	10	4
2	1	2.75	4	1	3	8.5	2
1	8	2.75	3	1	2	11	4
1	6	10	2.5	1	2	10	5
2	6	10	2	1	2	7.5	1.5
1	6	7	7	1	1	8	10
3	6	7	6				

There are 184 combinations in these 1,092 brands, not counting the differences in material of which they are composed. There are 37 combinations, embracing 833 brands, or 76 per cent of the whole number, which have 6 or more brands with identical combinations, as follows:

Fertilizers having identical composition.

Number of brands.	Phosphoric acid.	Ammonia.	Potash.	Number of brands.	Phosphoric acid.	Ammonia.	Potash.
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*
210	8	2	2	9	10	1	1
146	8	3	3	9	9	2.25	4
55	8	2.5	3	9	8	2.75	2.5
40	8	4	4	9	8	1	4
33	8	2.5	2	8	9	2.25	1
22	9	2.75	2	8	9	1	2
20	6	7	5	8	8	3	2.5
18	9	2	2	8	8	2	4
18	7	5	5	8	7	5	7
17	9	2	1	7	8	5	5
16	7	7	7	7	8	3	5
15	10	2	2	7	5	10	2.5
15	8.5	2	2	6	10	3	3
15	8	3	4	6	9	2.5	2
15	6	5	7	6	8	4	3
13	9	3	3	6	8	3	10
11	8	2	3	6	8	2.75	2
11	8	3	2	6	6	4	4
10	7	5	8				

Composition of special brands of fertilizers for special crops.

FOR TOBACCO.

[176 special brands.]

Number of brands.	Phosphoric acid.	Ammonia.	Potash.	Number of brands.	Phosphoric acid.	Ammonia.	Potash.
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*
2	9	3.5	5	5	8	3	5
7	9	3	3	6	8	3	4
2	9	2.75	2	49	8	3	3
1	9	2.5	3	2	8	2	3.5
4	9	2.5	2	3	8	3	2
1	9	2.75	4	1	8	2.75	4
4	9	2	2	1	8	2.75	2.5
1	8.5	3	4	13	8	2.5	2.5
1	8.5	3	2.5	21	8	2.5	3
1	8.5	2.75	2	2	8	2.25	2.5
1	8.5	2.5	2.5	2	8	2	4
1	8.5	2	2	2	8	2	3
1	8	4.75	4	20	8	2	2
1	8	4	7	1	6	3	3
1	8	4	5	1	5	6	9
1	8	4	3	1	5	4	6
1	8	4	2.5	2	4	4	6
9	8	4	4	1	4	3	6
1	8	3.5	5	1	4	3	5
1	8	3	10				

FOR COTTON.

[94 special brands.]

2	10	3	3	19	8	3	3
1	10	2	3	2	8	3	2
2	10	2	2	1	8	2.75	2
1	10	1	3	1	8	2.5	3
4	9	3	4	1	8	2.5	2
7	9	2.75	2	1	8	2.5	1.5
1	9	2.5	2	31	8	2	2
4	9	2	1	1	7	3.25	2.75
2	9	1	3	1	7	2	5
2	8.5	2	2	1	6	3	3
1	8	4	6	1	6	3	2.5
5	8	4	4	1	4	4	4
1	8	4	3				

FOR POTATOES.

[68 special brands.]

1	16	2	2.5	1	7	3.5	7
1	8	5	7	1	7	3	10
1	8	4.5	7	1	7	3	7
1	8	4	5	1	6	7	7
2	8	4	4	1	6	7	6
1	8	3	5	7	6	7	5
1	8	3	4	1	6	6	7
1	8	3	3	8	6	5	7
3	8	2	10	1	6	5	5
1	8	2	5	1	6	4	4
1	7	7.5	10	1	6	2	6
4	7	7	7	1	5	7	5
5	7	5	8	1	5	6	7
6	7	5	7	1	5	3	6
3	7	5	5	1	5	2	10
1	7	4	8	1	4	4	8
1	7	4	7				

Composition of special brands of fertilizers for special crops—Continued.

FOR CORN, GRAIN, AND GRASS.

[38 special brands.]

Number of brands.	Phosphoric acid.	Ammonia.	Potash.	Number of brands.	Phosphoric acid.	Ammonia.	Potash.
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*
1	11	3	4	3	9	1	2
1	10.5	2	5	1	8	3	6
1	10	2	4	12	8	2	2
1	10	2	2	1	8	1	3
1	10	1	5	2	6	3	3
4	10	1	3	2	5	10	2
3	10	1	1	1	5	2	5
1	9.5	2	1	1	4	7.5	2.5
1	9	2	1	1	1	8	10

FOR TRUCK CROPS.

[114 special brands.]

1	25	4	6	1	7	8	5
3	10	4	5	9	7	7	7
1	10	4	4	2	7	6	5
2	10	3	10	5	7	5	8
1	10	2	2	2	7	5	7
1	9	3.5	9	12	7	5	5
1	8	6	6	1	7	5	4
1	8	6	5	1	7	4	5
3	8	5	7	1	7	3	5
5	8	5	5	2	6	10	2
1	8	5	3	1	6	7	6
1	8	4.5	7	11	6	7	5
1	8	4.5	4	2	6	6	6
1	8	4	5	3	6	5	7
7	8	4	4	1	6	5	6
1	8	4	3	1	6	5	5
3	8	3	10	2	6	2.75	8
1	8	3	3	1	6	2.75	4
1	8	3	4	1	6	2	4.5
1	8	2.5	6	5	5	10	3
3	8	2.5	4	4	5	10	2.5
1	8	2.5	3	1	5	8	3
2	8	2	4	1	5	5	5
1	8	2	2.25				

ALABAMA.

The following extracts from the Alabama law and comments on the same are taken from the official bulletin giving the results of the fertilizer inspection for 1908:[a]

SEC. 6. No complete fertilizer, acid phosphate with potash, acid phosphate with nitrogen, or plain acid phosphate shall be sold in this State which contains less than 14 per cent plant food, namely: Available phosphoric acid, nitrogen calculated as ammonia, and potash, either singly or in combination; provided, that no complete fertilizer shall be sold in the State which contains less than one and sixty-five-hundredths per cent of nitrogen equivalent to 2 per cent of ammonia.

SEC. 10. No person, company, dealer, or agent shall sell, expose, or offer for sale, in this State, any pulverized leather, raw, steamed, roasted, or in any other form, either as a fertilizer or fertilizer material, without first having made full and explicit statement of the fact and registration with the commissioner of agriculture and industries and furnishing satisfactory proof that the nitrogen is sufficiently available and valuable for the purpose of [for?] which it is sold.

As a result of the enactment of the legislation referred to, the quality of the fertilizers found upon the market during the present season is considerably higher than heretofore, though the increase in plant food is chiefly in the phosphoric acid of the fertilizer. It is noted that owing to the change in the minimum limit of plant food some brand supplying the essential fertilizing constituents in entirely different proportions from those heretofore supplied by the brands upon the market have been listed for sale during the present season, and it seems quite probable that good results will follow the elimination of such fertilizers as the 10-1-1 goods. Fertilizers of this last-mentioned grade supply only 1 per cent each of potash and ammonia, and where the practice of applying 1 sack per acre of such a mixture has been adopted, only 2 pounds each of ammonia and potash are employed per acre of land. Inasmuch as many of our average soils, to a depth of 6 inches, will weigh about 2,000,000 pounds per acre, it will be seen that the application of such small amounts of ammonia and potash would add to the soil a relatively insignificant amount of plant food, and where these two particular constituents are needed by the soil they are usually needed in much larger proportions.

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[a] Annual Report on Fertilizers, August 1, 1908, Dept. of Agr., Montgomery, Ala.

The situation with respect to the guaranteed composition of the brands on sale in Alabama is simplicity itself as compared with the figures for the four States already mentioned. There are 364 brands of complete fertilizers on sale in the State, of which 341 brands, or 94 per cent, have the following guaranteed composition:

Composition of fertilizers.

Number of brands.	Phosphoric acid.	Ammonia.	Potash.	Number of brands.	Phosphoric acid.	Ammonia.	Potash.
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*
251	10	2	2	7	9	3	3
7	10	4	4	17	9	2	3
17	10	3	3	21	8	2	4
5	10	2	3	16	10	2	4

The formula 10-2-2 far outnumbers all others, being represented by 251 samples, or 70 per cent of the whole number.

The extreme range in composition in the 341 brands as shown above is 2 per cent phosphoric acid, 2 per cent in ammonia, and 2 per cent in potash. In the remaining 23 brands, the phosphoric acid goes up in three cases to 12 per cent and down to 6 per cent in two cases. Potash goes as low as 1 per cent in 3 brands. These are the extreme limits in composition of the complete fertilizers sold in the State. There are practically no special brands for special crops except cotton. The revenue from the sale of fertilizer tags for the fiscal year 1907-8 is given as $93,748.09.

GEORGIA.[a]

The Georgia department of agriculture discusses quite fully the composition of fertilizers and their relation to crops and actually gives a number of special formulas for special crops without, however, claiming to base these upon exact knowledge.

The following extract from the state fertilizer inspection law is interesting in this connection:

> SEC. 4. *Be it further enacted,* That the words "high grade" shall not appear upon any bag or other package of any complete fertilizer, which complete fertilizer contains, by its guaranteed analysis less than 10 per cent available phosphoric acid, 1.65 per cent nitrogen (equivalent to 2 per cent of ammonia), and 2 per cent of potash, or a grade or analysis of equal total commercial value; that the word "standard" shall not appear upon any bag or other package of any complete fertilizer which contains, by its guaranteed analysis, less than 8 per cent available phosphoric acid, 1.65 per cent nitrogen (equivalent to 2 per cent ammonia), and 2 per cent potash, or a grade or analysis of equal commercial value; that the words "high grade" shall not appear upon any bag or other package of any acid phosphate with potash which shall contain by its guaranteed analysis less than 13 per cent available phosphoric acid, and 1 per cent

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[a] Commercial Fertilizers and Chemicals, Bulletin No. 46, Georgia Department of Agriculture.

potash, or a grade or analysis of equal total commercial value; that the word "standard" shall not appear upon any bag or other package of any acid phosphate with potash, which shall contain, by its guaranteed analysis, less than 11 per cent available phosphoric acid and 1 per cent potash, or a grade or analysis of equal total commercial value; that the words "high grade" shall not appear upon any bag or other package of any plain acid phosphate which shall contain, by its guaranteed analysis, less than 14 per cent available phosphoric acid; and, lastly, that the word "standard" shall not appear upon any bag or other package of any plain acid phosphate which shall contain, by its guaranteed analysis, less than 12 per cent available phosphoric acid. It is hereby provided that no complete fertilizer, acid phosphate with potash, acid phosphate with nitrogen, or plain acid phosphate, shall be offered for sale in this State which contains less than 12 per cent of total plant food, namely: Available phosphoric acid, nitrogen when calculated as ammonia, and potash, either singly or in combination; provided, that in mixed fertilizers there shall not be claimed less than 1 per cent potash and 0.82 per cent nitrogen, when one or both are present in the same mixture.

The following rulings, based upon the inspection law, have been made by the commissioner:

Fourth. In case of goods containing 10 per cent available phosphoric acid, 0.82 per cent nitrogen, and 1 per cent potash, or such mixture 9-1.65-1, or 8-0.82-3, or other combinations which do not reach a total commercial value equal to that of the standard fertilizer, which is 8-1.65-2, such mixtures are not to be designated by any grade at all. Such goods may be offered for sale, and branded with any name the market desires to give, provided such name does not indicate that they belong to a high or standard grade.

Sixth. In the case of goods containing less than 1.65 per cent nitrogen they may be branded as "ammoniated" goods, "guano" or "fertilizer," or other words implying that the same is an ammoniated superphosphate, provided they contain not less than 0.82 per cent nitrogen.

Seventh. Goods containing 10 per cent available phosphoric acid, 0.82 per cent nitrogen, and 3 per cent potash can not be branded high grade, since they have not as high a commercial value as the legal high grade.

Eighth. No manufacturer has the right to print the word "ammonia" at all on his sacks.

Sixteenth. It is hereby ordered in consonance with the spirit of section 8 of the law, that no cyanogen compounds, dried muck or peat, wool waste, tartar pomace, or Mora meal, or other material not recognized by scientific authorities as being available sources of plant food, shall be used in any fertilizer sold in this State. All manufacturers are warned against purchasing unfamiliar fertilizer materials without first inquiring of this department as to their character.

Under the title "Misleading brand names and a little advice on purchasing," the following occurs:

It should be borne in mind always that state valuations are relative and approximate only, and are only intended to serve as a guide. It is much to be desired that farmers should study the analyses giving the actual percentages of plant food more, and pay no attention whatever to names and brands.

They should realize, for instance, that in nine cases out of ten brands known as "pure dissolved bone" contain not a particle of bone, but are made simply out of phosphate rock. They are every "whit and grain" as good as if they were made from bone, the available phosphoric acid from rock being just as available and identically the same as the available phosphoric acid from bone. The proof that such brands are not made from bone is that they contain no nitrogen, and if they were made from bone the percentage of nitrogen would be stated, and would be charged for. This is not [sic] only one instance of the folly of being influenced by names and brands—many might be given.

Remember that a multiplicity of brands is also expensive to the manufacturer, and you have to pay the cost in the long run. Study the market, select a time for purchasing when general trade in fertilizers is dull, club together with some of your neighbors, * * * and then order from a reliable manufacturer, stipulating, if you have a preference, just what materials the goods shall be made from, and especially the guaranteed percentage of nitrogen, phosphoric acid, and potash. Let the maker call it anything he pleases. * * *

The following proportions of plant-food elements for special crops are recommended by the Georgia agricultural department, although the caution is given that "every intelligent farmer will study his environment, his soil, and climatic conditions, and then use his best judgment:"

Proper proportion of plant food in fertilizers for different crops.

Crop.	Phosphoric acid.	Ammonia.	Potash.
	Per cent.	*Per cent.*	*Per cent.*
Cotton	10	6	3
Corn	8	3	5
Wheat	5	5	3
Celery	5	7	[illegible]
Potatoes	7	6	[illegible]
Beets and lettuce	5	6	[illegible]
Cabbage, cauliflower, cucumbers, and melons	5	6	[illegible]
Spinach	8	6	6
Radish and turnips	7	5	[illegible]
Asparagus	7	5	[illegible]
Eggplant and tomatoes	6	5	[illegible]
Onions	5	5	[illegible]
Sweet potatoes	7	3	[illegible]
Beans and peas	7	3	[illegible]

Coming now to a consideration of the composition of the brands actually on the market, we find on the whole an astonishingly small variation in percentage composition of mineral plant-food elements, although there is no possible way of determining how much variation there is in the material that went into the several brands.

There were 1,822 brands inspected, analyzed, and placed on the market for sale. Of these, 1,260 brands contain two or more plant-food elements (phosphoric acid, nitrogen, or potash) in 106 combinations. There are 26 combinations, however, embracing 1,143 brands, or 90 per cent of the total, in which each combination is represented by 6 or more brands. Of the 1,260 brands containing two or more elements, 1,259 contain phosphoric acid, and 1,163 brands, or 92 per cent, contain from 8 to 10 per cent of phosphoric acid, as follows:

Brands.		Phosphoric acid.
Number.	*Per cent.*	*Per cent.*
563	45	10
180	14	9
420	33	8

There are 77 brands, or 6 per cent, containing from 11 to 16 per cent, and 19 brands, or 2 per cent, containing from 7 to 5 per cent of phosphoric acid.

There are 1,259 brands containing potash, and 1,189 of these brands, or 93 per cent, containing from 1 to 4 per cent of potash, as follows:

Brands.		Potash.
Number.	*Per cent.*	*Per cent.*
291	23	4
249	20	3
605	47	2
44	8	1

In addition to these, there are 54 brands, or 4 per cent, containing from 5 to 8 per cent of potash.

There are 987 brands containing nitrogen, and of these 947 brands, or 96 per cent, contain from 1 to 4 per cent of ammonia, as follows:

Brands.		Ammonia.
Number.	*Per cent.*	*Per cent.*
34	3	4
85	9	3
696	70	2
132	14	1

In addition to these there are 17 brands, or 2 per cent, containing from 5 to 8.9 per cent of ammonia.

There are 855 brands, or 89 per cent of all the complete fertilizers, in which the variation in composition is from 8 to 10 per cent phosphoric acid and 1 to 4 per cent ammonia and 1 to 4 per cent potash, as follows:

Brands.		Phosphoric acid.	Ammonia.	Potash.
Number.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
255	27	10	2	2
242	26	8	2	2
90	9	9	2	3
44	5	10	3	3
34	4	10	1	3
28	3	10	2	4
23	2	8	1	3
23	2	10	1	1
23	2	9	1	2
18	2	10	4	4
18	2	8	2	4
18	2	9	2	1
14	1	9	3	2
13	1	9	2	2
12	1	8	3	3

Or, to put the matter in another way, there are 510 brands that differ only 2 per cent in the phosphoric acid, as follows:

Brands.	Phosphoric acid.	Ammonia.	Potash.
Number.	*Per cent.*	*Per cent.*	*Per cent.*
255	10	2	2
13	9	2	2
242	8	2	2

Then there is, in addition, 254 brands in which the extreme variation from the above is 1 per cent ammonia and 2 per cent potash, as follows:

Brands.	Phosphoric acid.	Ammonia.	Potash.
Number.	*Per cent.*	*Per cent.*	*Per cent.*
28	10	2	4
8	10	2	3
34	10	1	3
1	10	1	4
6	10	1	2
1	9	2	4
90	9	2	3
2	9	1	4
6	9	1	3
23	9	1	2
18	8	2	4
8	8	2	3
6	8	1	4
28	8	1	3

It is apparent, therefore, that 764 brands, or 80 per cent, of the complete fertilizers sold in the State of Georgia, have an extreme variation in composition so far as the official records show, and the manufacturers' guaranty claim of 2 per cent in phosphoric acid, 1 per cent in ammonia, and 2 per cent in potash. Furthermore, they are far below in ammonia and potash content the formulas proposed by the state inspection as given on a previous page of this report.

The following is a list of the 238 brands, omitting all duplicate names, having a guaranteed composition of 10 per cent phosphoric acid, 2 per cent ammonia (1.85 nitrogen), and 2 per cent potash:

List of brands having the guaranteed composition 10-2-2.[a]

Athens High Grade Guano.
A A A A High Grade Guano.
Acid and Meal Mixture.
Acme High Grade.
Adair's Soluble Pacific.
Alligator Ammoniated Bone.
American High Grade Fertilizer.
10-2-2 Ammoniated Bone.
Ammoniated Dissolved Bone.
Ammoniated Dissolved Bone and Potash.
Anderson's High Grade.
A. N. Hay's Fish Scrap High Grade.
A. & T. Ammoniated Dissolved Bone.
Atlantic High Grade Ammoniated Guano.
B. & B's High Grade.
Baker's High Grade.
Baker High Grade.
Ball Ground High Grade.
Baugh's High Grade Cotton and Truck Guano.
Bear High Grade Beef, Blood and Bone.
"Big Crop."
Birmingham Blood, Bone and Potash.
Birmingham High Grade Fertilizer.
Black Hawk High Grade.
Black Jack High Grade Guano.
Blood and Bone.
Blood and Bone High Grade.
Blood and Bone High Grade Fertilizer.
Blood and Bone High Grade Guano.
Blood, Bone and Potash.
Blood and Tankage Mixture.
Bowker's High Grade Fertilizer.
Boyd's Acme Soluble.
Boyd's Animal Bone Guano.
Brer Fox Fertilizer.
Brer Rabbit Fertilizer.
Buffalo High Grade.
Burke County Fertilizer.
Campton High Grade.
Capitola High Grade Guano.
Carlton's Best.
Carter's Boll Maker.
C. F. Sasser's Choice.
Chattahoochie.
Cherokee Fish High Grade.
Cherokee High Grade.
Cherokee High Grade.
Chickamauga Fish Scrap Guano.
Chickamauga High Grade Fertilizer.
Chickamauga Peanut Food.
Climax.
C. O. and F. Cos. High Grade.
10-2-2 Cotton Seed Meal Mixture.
Columbia High Grade Cotton Grower.
Coweta Fish Guano.
Coweta High Grade Fertilizer.
Compound Guano.
Cooper's High Grade.
Cooper's High Grade Guano.
Cotton Grower.
Cotton Meal Special.
Cotton Success.
Cotton Tail.
C. P. Lively Son's High Grade.
10-2-2 C. S. M. Mixture.
Davis High Grade Guano.
Daybreak Fertilizer.
Delaware River High Grade Fish Guano.
Eagle High Grade Guano.
E. B. Clark's Cotton Grower.
Empire High Grade Ammoniated Dissolved Bone.
Empire State Blood and Bone.
Etowah High Grade.
Eureka Ammoniated Bone.
Eutaw High Grade Golden Fertilizer.
Farm Bell High Grade.
Farmers Choice.
Farmers Friend.
Farmers High Grade.
Farmers Soluble High Grade.
Farmers Special Number 4.
Farmers Success.
Fayette Company High Grade.
Felton's Favorite.
Fish Compound.
Flannery's Staple Upland Cotton Grower.
Fowler Brother's High Grade Guano.
Fox Favorite.
Ft. Valley No Filler.
Furman's Fish Guano.
Furman's High Grade Fertilizer.
Georgia High Grade.
Georgia Keystone.
Georgia Test High Grade.
Gibb's Special Cotton Guano.
Gilt Edge High Grade Guano.
Gossett's Blood, Bone, and Meal.
Governor Guano.
Green County Oil Company's High Grade.
Green and Shadburn High Grade.
44 High Grade Guano.
Hammock's High Grade Formula.
Hampton High Grade Guano.
Heard County High Grade.

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[a] Commercial Fertilizers and Chemicals, Bulletin No. 46, Georgia Department of Agriculture, pp. 104-197.

Henry County High Grade Guano.
"High Grade."
High Grade Fertilizer.
High Grade Guano.
Hill Billy,
High Grade Ashepoo Fertilizer.
High Grade Bradley Soluble Guano.
High Grade Meal Mixture.
High Grade Victor Guano.
H. and H.'s High Grade C. S. M. Guano.
Hodge Home Mixture No. 3.
Halbrook Cotton Special.
Home Mixture No. 3.
Hoschton Pride and Big Indian Cotton Grower.
H. P. and B.'s Cotton Hustler.
Humber's Compound.
Independent High Grade.
Jackson County Favorite Cotton Producer.
Jacksonville High Grade Fertilizer.
Jasper High Grade.
Jefferson High Grade Complete Fertilizer.
Jefferson Meal, Acid and Potash Mixture.
Jenkin's Special Blood Guano.
Jewell's High Grade Guano.
J. J. and B. L. Bond and Company's High Grade.
Jones Merc Co. High Grade.
Kirk's High Grade Fish Guano.
Knight's Special.
Langford's Best.
Legal Tender High Grade.
Lewis' High Grade.
Lion High Grade Guano.
Lion Power Guano.
Lowry's High Grade Guano.
McCarty High Grade Corn Grower.
McCarty High Grade Cotton Grower.
McClure's High Grade Special.
McDonald and Weaver Acid and Meal.
McDuffie's High Grade Guano.
Mansfield Blood and Meal Formula.
Marriman's Cotton Boll.
Mastodon Ammoniated Soluble Phosphate.
Maxwell's Favorite.
Mississippi Sawyer.
Monarch Guano.
Moore's Special Pride.
Mortgage Killer.
Mortgage Lifter.
Navassa High Grade Fertilizer.
Neely's Burke County Fertilizer.
Newton County High Grade Guano.
North Georgia Pride.
N. and N.'s High Grade Ammoniated Guano.
Ober's Special Ammoniated Dissolved Bone.
Oil Mill High Grade Fertilizer.
Old Domian High Grade Guiano.
Old Time Fish Scrap Guano.
Oliver's Acid, Meal and Potash.
Oostanaula High Grade Blood and Bone.
Orange High Grade.
Our Union Ideal.
Owen's High Grade.
Ox Grade Ammoniated Bone.
Ox High Grade Fish.
Patapsca Guano.
Paulding County High Grade.
Paullins' Blood and Bone.
Pelican Guano.
Planter's High Grade.
Planter's High Grade Fertilizer.
Planter's Pride.
Planter's XXXX High Grade Blood, Bone and C. S. M.
Plow Share Brand Guano.
P. N. P's Complete High Grade Guano.
Pride of Fayette.
Pride of Morgan.
Read's Full Boll.
Read's High Grade Ammoniated Dissolved Bone.
Read's Special Compound C. S. Meal.
Red Cross High Grade Guano.
Red Elk High Grade No. 2.
Redwine's Special.
Rex High Grade.
Romulus High Grade Guano.
Royal High Grade Guano.
Royal Seal Guano.
Royster's High Grade Soluble Guano.
Royston High Grade.
Salmon's High Grade.
Sam Bowers' Acid, Meal and Potash Mixture.
Sam Bowers' High Grade.
Savannah Oil Mill High Grade Fertilizer.
Scott's Gossypium Phosphate.
Seabird High Grade Guano.
Senora High Grade.
Shirley's High Grade.
Smith's High Grade Blood and Bone.
Southern High Grade Fertilizer.
Special Mixture.
S. P. Thompson's High Grade Guano.
S. S. Grant High Grade Cotton Pusher.
S. S. Old Peruvian.
Stafford's Blood and Meal.
Stafford's High Grade Guano.
Strickland's High Grade.
Superior Meal Mixture.
Swift's Eagle High Grade Guano.
The Troup Company's Blood and Bone.
The Troup Company's Ocean Fish Scrap.
Three States High Grade Soluble Guano.
Tonowando Guano.
Tuscarora Big Crop Fertilizer.
Uncle Joe High Grade.
Uncle Remps' High Grade Guano.
Uncle Sam High Grade Ammoniated Guano.
Uruguay Ammoniated Bone.
Union Ideal Guano.
Upson County High Grade.
U. S. Meal Mixture.
V. C. Chesapeake Fish Guano.
V. C. High Grade Fish Guano.
V. C. Special High Grade Meal Fertilizer.
Vidalia Gold Medal Fertilizer.
Walton High Grade.
Warrior High Grade Complete Fertilizer.
W. A. Shore's High Grade.
W. D. Hawkins' High Grade Guano.
W. and H's Golden Union.
Wilson's Cotton Grower.
Winder High Grade Guano.
W. O. C. a pure Blood Guano.
Woods High Grade.
W. and T. High Grade Cotton Special.
Yellow Jacket Guano.

While the Georgia state department of agriculture recommends that from 200 to 500 pounds of fertilizer should be used per acre, it may be safely said that the amount applied by the great majority of farmers is about 200 pounds per acre. Out of the 764 brands, such an application would add from 16 to 20 pounds phosphoric acid, 2 to 4 pounds ammonia, and 4 to 8 pounds potash to an acre.

If we assume that this fertilizer goes into immediate and complete solution and is distributed in the soil moisture to a depth of 6 inches from the surface, and if we assume further that the weight of an acre of soil 6 inches deep is 2,000,000 pounds, and contains on the average 15 per cent of water, the maximum effect on the concentration of the soil moisture, disregarding the effect of the fertilizer on the solubility of the soil minerals and the absorbing power of the soil, will be approximately as follows: Phosphoric acid 53 to 67 parts per million, ammonia 7 to 13 parts per million, and potash 13 to 27 parts per million.

So far as the ammonia and potash are concerned, these concentrations are comparable with the normal concentrations of the soil moisture; for phosphoric acid the figures are considerably higher. But recent investigations of the physico-chemical relations between the solid soil and the soil water negative the assumption that the concentration of the soil solution would be increased by just the amounts added.

It may be assumed that in a majority of cases when used an application of 200 pounds of commercial fertilizer increases the productivity of the soil. An application of 400 pounds or 600 pounds is undoubtedly more efficient, and successful applications up to 3,000 pounds per acre are employed on tobacco, truck, and other special industries.

What immediately concerns us here, however, is as to the differences in composition in the brands of fertilizers sold and the relative efficiency of these brands when applied to any particular field or crop. We have seen that of the 987 brands of complete fertilizers sold in Georgia markets, 238 brands, or 24 per cent, have the composition 10–2–2. Several of the dealers and manufacturers put out 6 or 8 or more brands of this same composition. Do they differ and have different effects on the soil, and are they more efficient in connection with different crops? Under the state law, and trade conditions, they virtually have to be sold for the same price per ton. Officially, and so far as the public have certain knowledge, these 238 brands are all one and the same thing, and yet in all probability most of them differ in some essential character in composition and effectiveness by reason of the material contained or mode and condition of mixture. We know that the different carriers of phosphorus, nitrogen, and potassium have very different effects on soils and crops, and the time has come when it would be an advantage to the farmer and equally to the manufacturer to determine more nearly the relative effect of materials on soils and crops rather than to pursue longer the study of the elements; for, after all, it is the material which counts rather than the elements which go to make up the material. That is to say, it is not the potash, but the potash salt. There are nitrogenous bodies and potash salts both extremely toxic to plants, but of the common materials which can be safely used for crops some are more efficient on some soils and some on others, and more should be known about such matters.

Contrast now with the 238 brands of the composition 10–2–2, the 242 brands of the composition 8–2–2, making together more than half the brands of complete fertilizers sold in the State. Is there a real difference in effect of these two classes due to the difference of 2 per cent of phosphoric acid? Or put the case more strongly still. Take the extreme limits in composition on the great majority (80 per cent) of fertilizers sold in the State as given above. This would probably be 10–1–2 and 8–2–4, or we might take 10–2–4 and 8–1–2. The difference in the actual amount of nitrogen and potash is 100 per cent, and to make the same application double the amount of fertilizer would have to be applied in the one case as in the other. The difference is much less in the case of phosphoric acid, but apart from the question of the actual amount, does the difference in proportion shown by these small quantities have an appreciable effect on the soils and crops? In the above formulas, for example as extreme cases, we might apply 2 pounds per acre of ammonia with either 4 or 8 pounds of potash, or we might apply 4 pounds of ammonia with either 4 or 8 pounds of potash. Would these proportional and actual differences show in their relative effect on the soil and plant? We have reason to believe from laboratory and greenhouse experiments in growing plants in solutions of pure cultures and in soil extracts that they would, but we do not know enough about it, and it is in this direction that further investigations should be made to bring some order out of the problem of the practical application of fertilizers.

Issued September 28, 1909.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS—BULLETIN No. 59.
MILTON WHITNEY, Chief.

HEAT TRANSFERENCE IN SOILS.

BY
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WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1909.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF SOILS,
Washington, D. C., March 5, 1909.

SIR: I have the honor to transmit the accompanying manuscript of an article entitled Heat Transference in Soils, by Harrison E. Patten, of this Bureau, and to recommend its publication as Bulletin No. 59.

Respectfully,

MILTON WHITNEY,
Chief of Bureau.

Hon. JAMES WILSON,
Secretary of Agriculture.

PREFACE.

The dependence of so many of the physical properties of the soil upon the moisture content makes the study of the water-holding power of soils and distribution of water in soils of great theoretical and practical importance. With each and every soil there is a moisture content of exceptional interest, that is, where the water present is the maximum amount that can be held in the form of films over the surface of the soil grains and perhaps in the finest capillary spaces but is not sufficient to give any free water in the interstitial spaces. Practically, this amount of water can not be determined with any high degree of exactness, but all good greenhouse men, gardeners, etc., can approximate it for any given soil within a more or less narrow range of concentration. To them, this moisture content is known as the "optimum." Its significance has recently been discussed in bulletin No. 50 of this Bureau, and it has been shown that most if not all of the important physical properties of a soil show a critical change in passing through this optimum water content, from a lower to a higher content, or vice versa. This important moisture content, which is a characteristic constant for any particular soil, is in fact that at which the soil can be put in the best physical condition for plant growth; at which the most desirable "crumb structure" can be obtained; a maximum aeration and easiest penetration provided.

The primary object of the investigation described in the following pages was to determine the relation between the heat conductivity and moisture content of a soil with special reference to the importance of the "optimum water content." The analysis of the problem showed many experimental difficulties, which accounts for the meager progress hitherto made in the field. It has been shown that a soil does conduct heat better and more quickly with a moisture content near that recognized as the optimum, and the conditions which must be observed in future investigations on the relation of soil temperature to plant growth have been more clearly defined. The practical value of the work lies in pointing out the nature of the soil control which should be exercised in the planting of general farm crops to secure a warm seed bed and good germination, in the handling of cranberry marshes, and other special agricultural lines. By no means least is the value of this research in its relation to the theoretical viewpoint toward soil water which was developed in Bulletin No. 50, a viewpoint which has a rational experimental basis and is free from any arbitrary assumptions.

FRANK K. CAMERON,
In charge, Physical and Chemical Investigations.

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HEAT TRANSFERENCE IN SOILS.

INTRODUCTION.

Although measurement of soil temperature has been carried on in many countries for many decades, and possibly for many centuries, there seems to be no investigation on record giving the rate of flow of heat through soil under controlled laboratory conditions where the moisture content, packing (apparent specific volume), and effective specific heat are known. In some cases accurate daily readings of the soil temperature have been taken to a depth of 3 feet or more through a series of years, but no attempt made to measure, even roughly, the moisture content, the apparent specific volume, or the specific heat. Other observers have recognized the need of all these additional factors and have at times secured data on them under field conditions, but even then we can not calculate the heat conductivity of the soil with any degree of satisfaction from their readings, since the moisture content varies with the depth and we must take temperature readings at several depths to determine the temperature wave.

The investigators in this line of work have been interested mainly in ascertaining the temperature of the soil at given depths during the growing season. Some have tried the effect of various top dressings—manure admixtures, mulches, rolling, etc.—upon the soil temperature, and many of these results are valuable and reliable since they were gotten under comparable though undetermined conditions. Others, too, have recognized the part which the total quantity of available heat plays in the development of plants, and attempts to measure this heat have been made by integrating the air temperatures close to the ground and integrating the sunshine. Such calculations are also supplemented by an integration of the heat gained by the soil from day to day as the season progresses.

From another standpoint geologists and astronomers have made daily measurements of temperatures at regular depths in solid rock for periods even approaching half a century on one single series, and have accurately calculated the heat conductivity of the rock. But such values for the heat conductivity of a homogeneous or compact rock conglomerate do not help much in estimating the conductivity of a soil.

Much time has been devoted to the laboratory study of the heat relations of soils, such as heat capacity and the effect of soil moisture upon it; demonstration of the additive property for the heat capacity of a powder consisting of different minerals each with its own specific heat; the effect of top dressings and admixtures, etc. Especially interesting is the laboratory work of Petit[a] upon the penetration of frost into soils. He found that the phenomenon of supercooling, such as is observed in the freezing of water in the form of drops or in capillary tubes, also occurs in the freezing of soil water, and may be as great as 3° C. below the freezing point of water. The temperature to which soil water can be supercooled appears to be lower the lower the moisture content of the soil and the greater the energy with which the water is held by the soil. The passage of frost into the ground is fastest for quartz sand, slower for clay, and slowest for humus (peat). For continued frost the soil temperature sinks after freezing, the faster and the deeper the lower the moisture content of the soil, and conversely for the thawing of a soil. Living or dead vegetation or snow protects from frost and retards thawing.

The heat conductivities of dry powders and soils have been determined by numerous experimenters (see Tables XV, XVI, and XVII, but the effect of moisture upon the heat conductivity has been treated only qualitatively. Consequently an attempt is made in this paper to establish a quantitative relation between the heat conductivity of a powder and its moisture content. Since the apparent specific volume and effective specific heat of a powder are factors in determining its heat conductivity, these, too, were controlled. The diffusivity of the powder, of course, was found in order to calculate the heat conductivity.

The importance of such an investigation is apparent upon reading the reports of experiment stations generally, both in this country and abroad, since large sums of money and patient observation and experimentation are involved in the attempt to ascertain the relation of temperature in air and in soil to crop growth. So long as the factors which control heat conduction remain in doubt as to magnitude and direction of influence much of this field work upon soil temperatures will be in vain.

Usually the heat conductivity of the earth's crust has been determined by taking the temperature of the earth at different depths as affected by the alternate heating and cooling at the surface, due to the change from night to day, and in a greater degree as affected by the progression of the seasons.

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[a] Forsch. Geb. Agr. Phys., **16**, 285 (1893).

Such measurements give the temperature wave at each depth very well for the particular locality studied, and when the specific heat of the dry soil, the per cent of water, and the specific volume (or packing) are known, one may calculate the heat conductivity of the soil. This calculation, however, involves the treatment of a periodic function which only approximates a *sine curve*, since it is modified by a damping term as well as by other disturbing factors. Consequently, the heat conductivity calculated in this manner is at best an approximation. Further, as the heat wave penetrates into the earth, distillation of moisture takes place accompanied by a change in packing, so any method of measuring heat conductivity which requires the soil to be subject to a difference of temperature for a short period can not be expected to give even approximately accurate results.

The selection of a method for measuring the passage of heat through a moist soil under laboratory conditions is a case of having to choose the least of several evils. There is no good method. A few of the experimental difficulties are discussed below. Briefly, the situation is this: If the heat be measured by extracting it from the soil, distillation ensues and the soil-crumb structure is altered; if heat be added, the same process is gone through in the reverse sense; if alternate heat and cold be applied, the soil changes its packing and may change its moisture content. In the face of these conditions it was decided to supply heat, from an infinite source at a constant temperature, to the end of a soil column and take the rate of rise of thermometers at regular distances down the column, and base a calculation of the heat conductivity upon the behavior of that portion of the soil which was sufficiently removed from the source of heat to be very little changed by distillation of its moisture and yet close enough to show the influence of the heat. There are grave defects in this method, as shown in the discussion of sources of error below, but it has served to give a fairly quantitative idea of the effect of soil moisture upon the heat conductivity of soils.

METHOD.

In general, when a column of material is heated at one end the temperature rises gradually all along the column. If the heated end be maintained at a constant temperature, each cross section of the column will finally attain a steady temperature and transmit all of the heat it receives. Thus let one end of the bar in figure 1 be kept at 100° C. and the other at 0° C. Then after a long time the temperature at any given point along the bar will be proportional to its distance from the end. If, for instance, the bar be exactly 100 cm. long, its temperature will drop at the rate of 1 degree for every centimeter passing from the heated end.

To calculate the quantity of heat which flows through any part of the bar, consider any small section of area, A, and thickness, Δx, at x cm. from the heated end, figure 1.

Let θ be the temperature at the surface of the cross section A, at a distance x from the source of heat. Then the flow of heat per unit of time through this surface A will be

$$-KA\left(\frac{d\theta}{dx}\right). \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Where K is the *heat conductivity* of the material which composes the bar, and is by definition *numerically equal to the quantity of heat which flows per unit of time through unit area of a plate of unit thickness having unit difference of temperature between its faces,* and where $\left(\frac{d\theta}{dx}\right)$ is the *temperature gradient;* that is, the change of temperature per unit thickness. The negative sign indicates that the temperature falls as x increases.

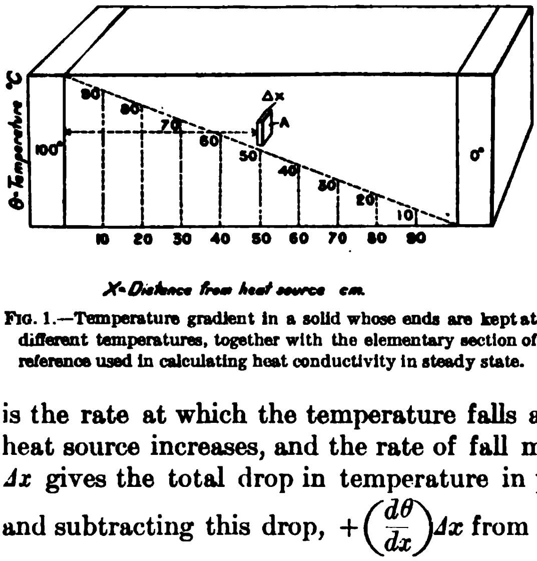

FIG. 1.—Temperature gradient in a solid whose ends are kept at different temperatures, together with the elementary section of reference used in calculating heat conductivity in steady state.

The temperature at the farther surface of the cross section A, at distance $x + \Delta x$ from the heat source will be lower than θ and is given by the expression $\theta - \left(\frac{d\theta}{dx}\right)\Delta x$, since $-\left(\frac{d\theta}{dx}\right)$ is the rate at which the temperature falls as the distance x from the heat source increases, and the rate of fall multiplied by the distance Δx gives the total drop in temperature in passing from x to $x + \Delta x$; and subtracting this drop, $+\left(\frac{d\theta}{dx}\right)\Delta x$ from the temperature θ at the point x, gives the temperature at $x + \Delta x$, when Δx is taken so small that the temperature fall is practically constant between x and $x + \Delta x$. Consequently the flow of heat through the cross section A at the point $x + \Delta x$ will be

$$-KA\left[\frac{d}{dx}\left(\theta - \left(\frac{d\theta}{dx}\right)\Delta x\right)\right] \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Evidently the excess of what flows in at one face of the element over what flows out at the other will be

$$(1) - KA\left(\frac{d\theta}{dx}\right), \text{ less } (2) - KA\left[\frac{d}{dx}\left(\theta - \left(\frac{d\theta}{dx}\right)\Delta x\right)\right] =$$

$$-KA\frac{d^2\theta}{dx^2}\Delta x \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

From the fact that $\frac{d^2\theta}{dx^2}$ is zero when the temperature gradient is constant along the bar, it follows that in the steady state this excess of heat likewise is zero, provided the surface of the bar is insulated, thus preventing radiation of heat from the edges, whose depth is Δx of the cross section A. That is to say, as much heat flows out of the surface of cross section A at $x + \Delta x$ as enters the surface at x.

For the case where the surface is not insulated,[a]

$$KA\left(\frac{d^2\theta}{dx^2}\right)\Delta x = Ep\Delta x\theta,$$

where E is the surface emissivity of the bar and p is the perimeter of the element, $p\Delta x$ being the surface of the element of cross section A, and width Δx which is radiating heat.

Forbes's[b] method of determining heat conductivity avoids the solution of Fourier's equation and the hypotheses (*a*) of constant heat conductivity, and (*b*) of Newton's law of cooling, upon which Fourier's equation is founded. Forbes determines the heat conductivity directly in terms of the quantities which enter into its definition.

Forbes's method involves two separate experimental procedures:

(*a*) The *statical experiment*, which consists in maintaining one end of a long bar at a constant temperature until the temperature at each point along the bar has ceased to change. Thus the temperature gradient along the bar is determined.

(*b*) The *dynamical experiment*. An iron bar similar in all respects to that employed in the statical experiment, but much smaller (20 inches long by 1¼ inches square section), is heated to a known temperature and its rate of cooling observed, the object being to determine the rate at which any element of surface of the statical bar loses heat.

From the results of these two experiments, together with the specific volume (the reciprocal of the density) and the specific heat of the iron, the flow of heat across any portion of the statical bar may be evaluated, thus giving the heat conductivity.

Forbes's method postulates that the material under examination suffer no marked change in structure during the experiment. Consequently this method is applicable to the determination of the heat conductivity of soils and powders only by radical modification, since it is impossible to obtain a powder twice in the same condition as to packing, moisture content, flocculation, etc.

This modification of Forbes's method consists in measuring simultaneously the *rate* of *temperature rise* in a soil at regular distances from the constant temperature heat source, and the ***difference of temperature gradient*** which causes this rise.

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[a] Cf. Preston, Theory of Heat, ed. 1904, pp. 632–633.

[b] Phil. Trans. Roy. Soc. Edinburgh, 23, 133, April, 1862. See also Preston, Theory of Heat, 1904, p. 640, from which this reference is cited.

Consider an insulated box of dry soil one end of which is maintained at a constant temperature of 100° C., uniform over the cross section, figure 2, and the other end maintained at a lower temperature, say 0° C. Then, after a long period the temperature along the box will be proportional to the distance from the heated end. If the box is exactly 100 cm. long, the temperature will decrease 1 degree for every centimeter, when the soil temperature at every point has ceased to change.

Before the box of soil attains this steady state the temperature at each point in the soil is changing and the fall of the temperature along the box at any instant will be represented by some such curve as curve 2, figure 2. In this condition the heat which flows in at one surface of the element A is greater than that which flows out at the surface farther removed from the heat source. If the mean temperature of the element rises by an amount $d\theta$ in a time dt, a quantity of heat, $Ac\left(\frac{d\theta}{dt}\right) \varDelta x$ is spent per second in raising the temperature of the soil, where c is the thermal capacity of the soil—that is, its effective specific heat divided by its apparent specific volume—A is the area of the element, and $\varDelta x$ its thickness.

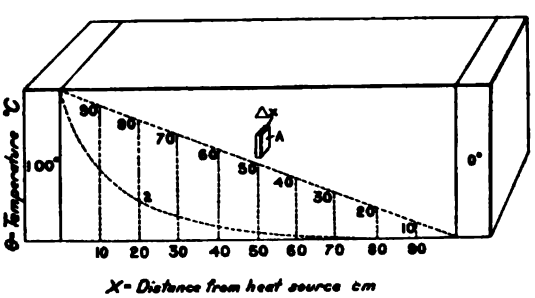

FIG. 2.—Temperature gradients in steady state and in unsteady state.

The excess of heat entering the element over the heat which flows out at the farther surface of element $A\varDelta x$, is now made up of two terms, one, due to surface radiation over the surface presented by the edge $\varDelta x$ with perimeter, p; the other, due to heat used in raising the temperature of the soil element, $A\varDelta x$. Thus,

$$AK\left(\frac{d^2\theta}{dx^2}\right)\varDelta x = Ep\,\varDelta x\theta + Ac\left(\frac{d\theta}{dt}\right)\varDelta x.$$

If the soil box be insulated, the emissivity (E) may be taken as zero and the equation becomes

$$\frac{K}{c}\left(\frac{d^2\theta}{dx^2}\right) = \frac{d\theta}{dt}$$

$$\text{or } K = \left(\frac{d\theta}{dt}\right)c \div \left(\frac{d^2\theta}{dx^2}\right).$$

Consequently, to determine the absolute heat conductivity of a soil, it is necessary to know $\left(\frac{d\theta}{dt}\right)$, $\left(\frac{d^2\theta}{dx^2}\right)$, and c. The diffusivity is given by dividing $\left(\frac{d\theta}{dt}\right)$ by $\frac{d^2\theta}{dx^2}$.

The rate $\left(\frac{d\theta}{dt}\right)$ at which the temperature rises with time at a known distance x from the heat source is read on a thermometer and with a stop watch.

$\frac{d^2\theta}{dx^2}$ is the rate at which the fall of temperature along the box decreases on passing from the heated end. This is found by three successive steps: (*a*) The rate of rise with time is read on each of a series of thermometers placed in the central axis at known distances from the heated end of the soil box. These readings are then plotted, using temperature as ordinates and time as abscissas. Such a series of curves is shown in figure 3. (*b*) At the particular instant, t, when a thermometer (say No. 5 thermometer at a distance of 5 cm. from the heat source) shows a rate of rise of $\left(\frac{d\theta}{dt}\right)$ (which may be from 0.3° to 1.0° per minute), a cross section of the curve in figure 3 is taken. This means that the reading of each thermometer at the instant t is taken from its curve in figure 3. With these values, we can construct a curve showing the fall of temperature along the soil box at the instant t, i. e., the temperature gradient, as shown in figure 4. (*c*) To calculate $\left(\frac{d^2\theta}{dx^2}\right)$, the rate of change of the temperature gradient at 5 cm. from the heat source, the gradient $\left(\frac{d\theta}{dx}\right)$ is taken from the curve

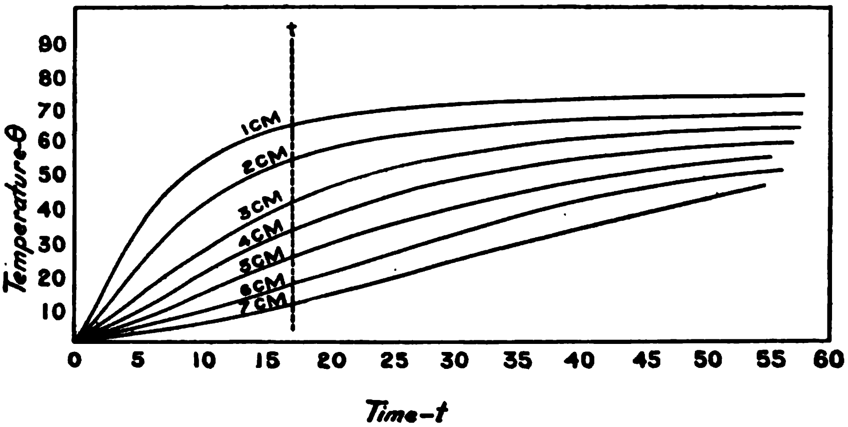

FIG. 3.—Temperature-time curves for the general case.

in figure 4 at 4.5 cm. from the heat source, and again at 5.5 cm. from the heat source. The difference $\left(\frac{\Delta\theta_{4.5}}{\Delta x_{4.5}}-\frac{\Delta\theta_{5.5}}{\Delta x_{5.5}}\right)$ divided by Δx (which here is 1 cm.) gives $\frac{\Delta^2\theta}{\Delta x^2}$ at 5 cm.

The value of c, the thermal capacity of the soil, is found by dividing the effective specific heat of the soil by its apparent specific volume. The specific heat of a moist soil is obtained by adding the thermal capacity of the solid portion of the soil to the thermal capacity of the water, the contribution of the gases to the heat capacity of the soil being very small. The apparent specific volume is determined by weighing a known volume of the moist soil in the condition of packing in which it enters into the experiment, where its conductivity is to be determined.

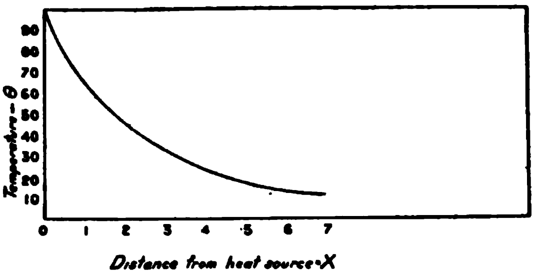

FIG. 4.—Temperature gradient for unsteady state.

In the foregoing description of the method used in determining heat conductivity, it is assumed, for the sake of simplicity, that the soil moisture remains evenly distributed throughout the box during the determination. In practice, however, the soil moisture passes from regions of higher to regions of lower temperature, thus causing the heat conductivity to vary (1) with the *time* at any one soil element, and (2) with the *distance* from the heat source, the dryer portions of soil near the heat source conducting less well than the moist soil farther out. The effect of this drying out of soil upon the temperature gradient is shown in figure 5. Curve 1 illustrates the fall in temperature along the box, supposing the soil moisture remains evenly distributed; curve 2 shows the effect of the drying out near the heat source upon the fall of temperature along the box; the poorly conducting dry layers of soil near the heat source require a high temperature gradient to force the heat through

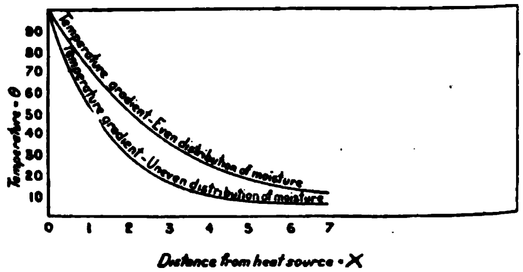

FIG. 5.—Effect of uneven distribution of moisture upon temperature gradient in unsteady state.

them, consequently the temperature drop along the box is at first rapid and then very gradual.

It was to avoid this very drying out effect that the above-described method was chosen, consequently, the *rate of temperature rise with time,* $\left(\frac{d\theta}{dt}\right)$, *and rate of change in temperature gradient* $\left(\frac{d^2\theta}{dx^2}\right)$, are taken for a point in the soil so far removed from the heat source that no great disturbances in the moisture content or packing have yet taken place. It is this instantaneous reading which gives validity to this method, since any long-continued heating will change completely the condition and the heat conductivity of the soil.

APPARATUS.

The apparatus used in this method consists in the main of three distinct features: (1) The heat source; (2) the soil box; and (3) the mechanical packing apparatus.

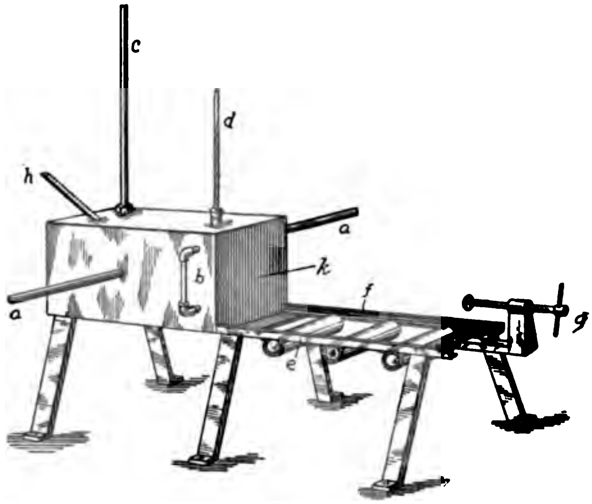

Fig. 6.—Heat source used in this investigation.

(1) The heat source is a heavy rectangular brass tank, 17 cm. wide, 12 cm. deep, and 20 cm. long, insulated with asbestos and felt on five sides, one end being exposed to serve as a heat-contact. The tank is maintained at a constant temperature, near 100° C., by boiling water in it and allowing the steam to escape (*h,* fig. 6) at atmospheric pressure. For lower and higher temperatures, different liquids may be used. The liquid in the tank is very conveniently heated by a copper coil carrying live steam (*a,*) which passes horizontally through the tank. The steam exhausts into a drainpipe where it is condensed by running water. The level of the water in the tank is shown by the gauge *b,* and as the water boils away, the supply is replenished by the feed-pipe, *c.* The temperature of the tank is given by the thermometer, *d; e* and *f* are skids for the soil box, and *g* is a screw clamp serving to press the soil box firmly in place against the heat source.

(2) The soil box is built of pine wood boiled in paraffin and painted with asphaltum. One end is made of copper. Externally it has a coating of asbestos board cemented to the wood. The end cross section inside the box is 10 by 10 cm. Centigrade thermometers, reading to 110°, are inserted through rubber stoppers in the sides of this box at intervals of 1 cm., the even positions alternating with the odd positions on opposite sides of the box, thus, numbers 1, 3, 5, 7 are on the right side of the box, and numbers, 2, 4, 6 on the left side (fig. 8). The thermometer bulbs are ranged along the central diameter of the box, which is perpendicular to the plane of the heat source. For some of the determinations thermometers were placed above and below this central diameter to ascertain the effect, upon the rate of the temperature rise with time, of departure from this central diameter.

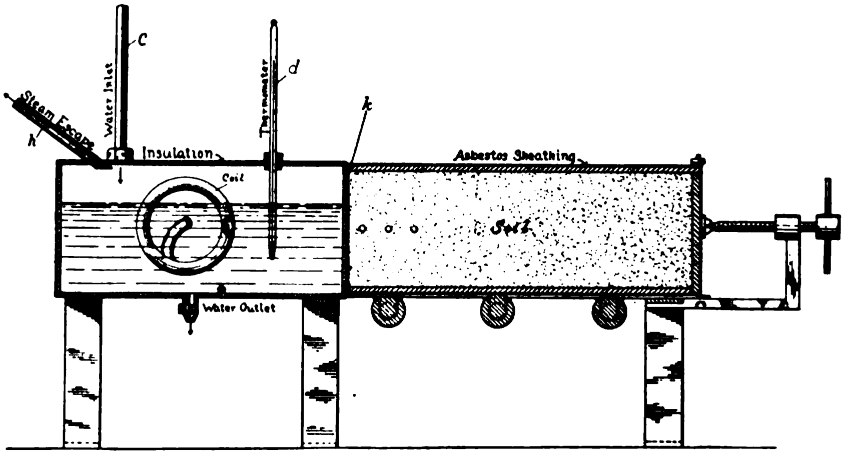

FIG. 7.—Longitudinal section of heat source with soil box in position.

In making a determination the soil box is fitted with the thermometers and then filled with soil of definite moisture content from the mechanical packing device to be described below. The soil box is then allowed to stand until the thermometers are nearly in a steady state at room temperature and the reading of each thermometer at "zero" time taken. The copper end of the soil box (*K*, figs. 6 and 7) is then placed against the heat source, a stop watch pressed at the instant of contact, and readings of time and temperature taken from each thermometer

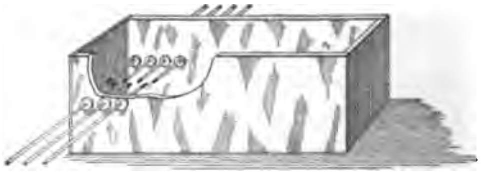

FIG. 8.—Soil box, showing arrangement of thermometers.

during a period which may cover twenty minutes or two hours, depending upon the heat conductivity of the soil.

(3) The mechanical packing apparatus used has been pictured and described in a previous bulletin[a] and is reproduced in figure 9. It consists of an electric motor whose shaft bears an eccentric collar *E* fitting into a hole in the end of a sieve *S*. When the motor is going the sieve vibrates rapidly at its lower end, the upper end being held in place by wire hooks *R* which engage a support and are kept in place by the pendant weight *W*. The tin false bottom *T* feeds the soil to the screen, which had three meshes to the centimeter in the work here presented. The soil box (fig. 8) may thus be filled with soil under definite mechanical conditions. In all the experimental determinations of heat conduction the soil was packed by means of this device, the height of the sieve above the soil box being always the same.

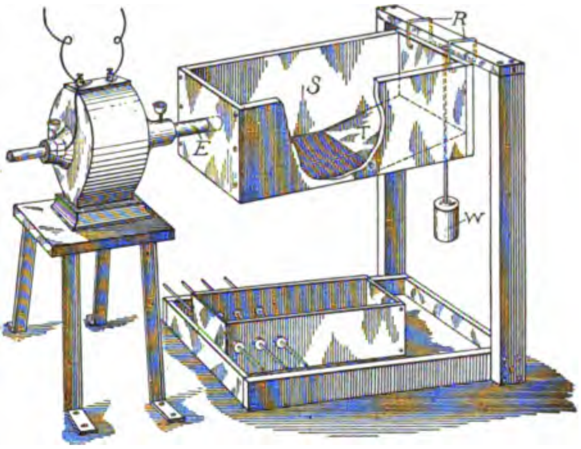

FIG. 9.—Mechanical packer, showing soil box below.

GENERAL SURVEY OF EXPERIMENTAL WORK.

In order to ascertain the effect of water upon the heat conductivity of a powder whose grains are all of the same material, experiments were made using a coarse grade of crushed quartz at seven different moisture contents. Similarly a fine quartz flour was used at ten different moisture contents. With these two series of experiments in hand giving the change of heat conductivity and diffusivity produced in a single-substance powder by addition of various quantities of water, we are in a position to try the similar effect of moisture in more complex powders, such as soils.

A sand from the bottom of the Hudson River at five different moisture contents was then studied; next, Podunk fine sandy loam at eight moisture contents; Leonardtown silt loam at ten moisture contents; and a muck soil containing 25 per cent of organic matter at eight moisture contents. Also Hagerstown loam, Galveston clay, and a No. 4 sand, a separate from a mechanical analysis, were studied in less detail.

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[a] Moisture Content and Physical Condition of Soils. Cameron and Gallagher, Bulletin No. 50, Bureau of Soils, U. S. Dept. Agr., 1908, p. 60.

With a different spacing of thermometers from that given above (where they were placed 1 centimeter apart) Norfolk sand in air-dry condition was also used. Finally, to determine how the heat conductivity of an air-dry powder varies with the size of grain, under the same conditions as to packing, a series of experiments with carborundum powder was carried out.

EXPERIMENTAL RESULTS.

COARSE QUARTZ.

The sample of quartz powder used was largely medium sand, as shown by the following mechanical analysis, which is the mean of several separate analyses:

TABLE I.—*Mechanical analysis of coarse quartz powder.*

Diameter of grain.	Conventional name.	Per cent.
Millimeters.		
2 -1	Fine gravel	0
1 -0.5	Coarse sand	14.74
0.5 - .25	Medium sand	58.22
.25 - .1	Fine sand	26.11
.1 - .05	Very fine sand	.61
.05 - .005	Silt	.00
.005- .000	Clay	.00

The basal observations of the temperature at distances of 1, 2, 3, 4, 5, 6, and 7 cm. from the heat source at various intervals of time are given in Table II. Six similar sets of observations were made for the same quartz flour at six other moisture contents. The experimental data are not presented at this time, but the tables are on file in the Bureau of Soils and are available to the scientific public.

TABLE II.—*Fundamental data for determination of heat conductivity and diffusivity.*

[Name of soil: Coarse quartz.]

RATE OF RISE OF TEMPERATURE IN SOIL AT DIFFERENT DISTANCES FROM A STEADY SOURCE OF HEAT.

1 cm. from heat source.			2 cm. from heat source.			3 cm. from heat source.			4 cm. from heat source.		
Time.		Temp.	Time.		Temp.	Time.		Temp.	Time.		Temp.
m.	*s.*	° *C.*	*m.*	*s.*	° *C.*	*m.*	*s.*	° *C.*	*m.*	*s.*	° *C.*
0	10	19.6	0	15	19.8	1	40	19.7	1	30	19.95
4	00	19.8	4	10	19.8	4	35	19.7	4	40	19.95
5	20	25.4	5	30	20.1	7	45	20.1	5	55	19.95
5	45	27.8	8	45	26.1	8	40	20.6	6	30	19.95
6	07	30.0	10	00	29.0	9	25	21.1	8	00	20.00
7	35	37.5	12	20	33.7	11	30	22.9	9	35	20.2
9	15	44.0	13	55	36.7	12	35	24.0	11	40	20.7
11	25	50.0	19	00	44.1	14	10	25.7	12	40	21.1
12	30	52.5	28	25	53.0	16	25	28.3	13	25	21.4
13	45	55.0	30	30	54.5	18	45	30.7	14	15	21.8
16	50	59.8	33	45	56.5	22	30	34.5	15	00	22.3
18	50	62.2	36	40	58.0	28	15	39.2	15	30	22.5
22	40	65.8	39	45	59.4	30	40	41.1	16	10	22.8
28	25	69.5	41	15	60.0	35	30	44.2	17	00	23.4
30	15	70.5	43	45	60.8	41	30	47.1	17	40	23.8
32	50	71.7	46	10	61.6	45	10	49.1	18	00	24.0
36	00	73.0	49	30	62.8	46	20	49.7	18	30	24.4
39	30	74.0	52	10	63.6	49	55	51.0	19	25	25.0
40	00	74.3	54	50	64.2	52	30	52.0	20	50	26.0
43	30	74.6	57	00	64.8	56	45	53.5	22	30	27.2
46	00	75.4	59	45	65.5	58	25	54.0	23	20	27.8
49	45	76.5	62	20	66.0	60	00	54.5	24	20	28.5
52	10	77.0	64	20	66.5	62	10	55.0	25	12	29.0
55	00	77.6	68	00	67.1	64	30	55.7	25	55	29.5
57	15	78.0	72	15	68.0	67	15	56.4	26	30	29.8
59	30	78.4				68	15	56.7	27	08	30.35
62	30	78.9				70	00	57.5	27	50	30.7
64	10	79.0				72	50	57.8	28	55	31.4
67	50	79.5							30	50	32.7
69	50	79.8							31	30	33.0
72	40	80.0							33	15	34.1
									34	30	34.8
									35	15	35.2
									37	45	36.5
									38	45	37.0
									40	30	38.0
									43	10	39.0
									44	30	39.6
									45	45	40.1
									46	45	40.5
									47	45	41.0
									49	00	41.4
									50	00	41.8
									51	40	42.3
									52	45	42.7
									54	25	43.3
									56	30	44.0
									58	10	44.5
									60	40	45.3
									62	00	45.7
									63	40	46.1
									64	40	46.4
									66	30	47.0
									68	30	47.4
									69	00	47.6
									72	00	48.3
									72	45	48.6

TABLE II.—*Fundamental data for determination of heat conductivity and diffusivity*—Con.

RATE OF RISE OF TEMPERATURE IN SOIL AT DIFFERENT DISTANCES FROM A STEADY SOURCE OF HEAT—Continued.

5 cm. from heat source.		(Beckmann.)		6 cm. from heat source.		7 cm. from heat source.	
Time.	Temp.	Time.	Temp.	Time.	Temp.	Time.	Temp.
m. *s.*	° *C.*	*m.* *s.*	° *C.*	*m.* *s.*	° *C.*	*m.* *s.*	° *C.*
0 20	19.45	0 00	0.715	0 50	19.3	0 35	19.5
1 50	19.45	1 00	.715	3 00	19.3	7 10	19.5
4 20	19.45	3 00	.715	4 30	19.3	10 00	19.5
5 45	19.45	3 45	.715	7 45	19.3	15 40	19.65
7 00	19.45	4 55	.715	8 20	19.35	19 35	19.8
8 00	19.45	6 20	.715	9 40	19.35	28 35	21.0
8 55	19.45	7 25	.715	10 40	19.4	29 45	21.1
10 00	19.5	8 15	.715	11 10	19.4	34 45	22.3
10 50	19.55	9 00	.715	14 25	19.45	41 50	24.0
11 50	19.65	10 15	.745	15 10	19.55	45 00	25.0
12 55	19.7	11 00	.775	16 30	19.6	47 10	25.5
15 35	20.0	12 00	.835	17 25	19.7	50 40	26.5
16 10	20.05	12 50	.900	18 20	19.8	56 00	27.9
17 00	20.3	13 30	.975	19 15	19.95	58 45	28.7
17 45	20.50	14 43	1.145	20 35	20.2	60 30	29.0
18 00	20.6	15 03	1.200	21 15	20.3	62 45	29.6
19 35	21.0	15 53	1.350	22 20	20.6	65 10	30.1
20 55	21.5	16 37	1.500	23 05	20.7	67 10	30.7
22 55	22.2	17 15	1.650	24 35	21.1	69 30	31.2
23 30	22.5	17 51	1.800	25 25	21.3	72 25	32.0
24 28	22.9	18 15	1.900	26 15	21.6	74 00	32.3
25 34	23.3	19 07	2.150	26 55	21.7		
26 35	23.8	19 48	2.350	28 05	22.1		
27 12	24.0	19 58	2.400	31 45	23.3		
27 55	24.4	20 07	2.450	33 30	24.0		
30 00	25.4	20 16	2.500	35 45	24.8		
31 00	25.9	20 26	2.550	37 00	25.3		
32 00	26.3	21 02	2.750	39 00	26.0		
33 00	26.8	21 20	2.850	40 45	26.7		
34 00	27.2	21 30	2.900	42 00	27.2		
35 00	27.7	22 03	3.100	43 20	27.7		
36 15	28.1	23 00	3.450	44 40	28.0		
37 15	28.6	23 33	3.650	46 55	28.9		
38 30	29.2	23 41	3.700	48 00	29.3		
40 15	30.0	23 49	3.750	49 20	29.8		
41 25	30.5	23 57	3.800	50 30	30.1		
42 15	30.85	24 03	3.850	52 00	30.6		
43 00	31.1	24 12	3.900	53 15	31.0		
44 00	31.5	24 43	4.100	54 35	31.4		
45 30	32.1	24 58	4.200	56 10	32.0		
46 30	32.5	25 05	4.250	59 00	32.8		
47 30	33.0	25 44	4.500	60 00	33.5		
48 40	33.3	25 59	4.600	63 00	34.0		
50 15	33.9	26 22	4.750	64 55	34.6		
51 30	34.3	26 43	4.900	66 45	35.0		
53 00	34.9	26 57	5.000	69 15	35.7		
54 10	35.2	27 17	5.150	73 40	36.8		
55 10	35.5	27 26	5.200				
56 20	35.9	27 33	5.250				
57 50	36.3						
59 10	36.8						
60 15	37.0						
61 45	37.5						
64 50	38.3						
66 00	38.6						
67 30	39.0						
68 45	39.3						
71 30	40.0						
74 15	40.6						

Temperature of heat source, 98.8.
Heat applied at 3 minutes 30 seconds.
Apparent specific volume 0.601.

For Table II the quartz powder was air dry. For the remaining six determinations the quartz was moistened and thoroughly well mixed by hand and by several passages through the screen of the mechanical packer (fig. 9). It was then allowed to fall into the soil box (fig. 8) from the mechanical packer and a volume weight taken for part of the same sample by allowing it to pack from the screen of the packer into a glass crystallizing dish of known volume, which was weighed after scraping the top of the quartz powder flush with the edge of the dish. The moisture content of this sample in the crystallizing dish was then obtained by evaporating first on a steam bath and finally to constant weight in a toluene oven at 110° C. The thermometers in the soil box were read, and if their temperatures were close together and near the room temperature, the box was applied at once to the source of heat and the time-temperature readings begun. In some experiments the thermometers were read for some time before applying the box to the source of heat.

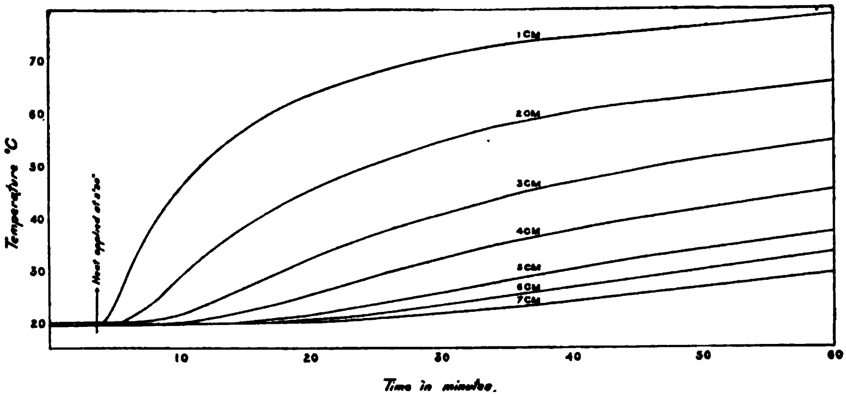

FIG. 10.—Temperature-time curves for air-dry coarse quartz powder.

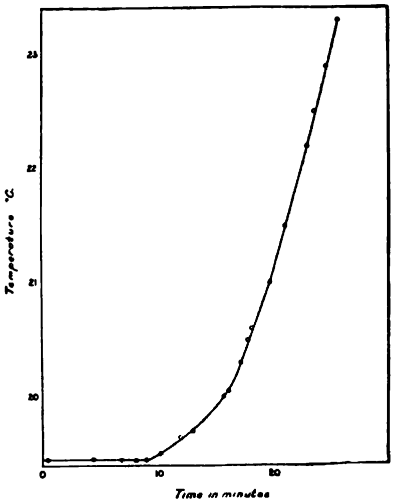

FIG. 11.—Temperature-time curve for air-dry coarse quartz powder, No. 5 thermometer, showing period of straight line rise.

In some of the experiments a Beckmann differential thermometer was inserted at a distance of 5 centimeters from the source of heat in order to read the temperature differences more accurately at this point. The thermometers used for the general work were graduated to 1° C., and could be read by means of a hand lens to 0.1°. Their range was −10° to +110° C. The bulb of each thermometer was about 2.7 cm. long and 0.5 cm. in diameter. The time-temperature curves were plotted with temperature as ordinates and time as abscissas, the readings for all seven thermometers at one moisture content appearing on the same sheet, figure 10. With these curves as a basis the fall in temperature along the soil box may be interpolated for *any instant* and these temperature values plotted as a function of the distance x of each thermometer from the source of heat, figure 12. The particular instant at which this gradient curve, figure 12, is to be taken is found by plotting on a larger scale than figure 10 the time-temperature curve for the thermometer 5 cm. distant from the heat source, as shown in figure 11. Here it is seen that after a short period the temperature rises at a nearly constant rate, −0.433° C. per minute in this particular experiment. The instant at which this constant rate is established is taken as the time at which to read the temperature gradient from the fundamental curve given in figure 10. From this temperature gradient, as plotted in figure 12, a value of the *rate* of *change* of *temperature gradient* with *distance* from the heat source at the particular instant, t, may be found, i. e., $\frac{d^2\theta}{dx^2}$, either graphically or analytically. These values, $\frac{d\theta}{dt}$ and $\frac{d^2\theta}{dx^2}$, together with the apparent specific volume and the effective specific heat, are assembled in Table III, and from them the absolute heat conductivity and diffusivity are calculated and given in the columns so designated. The curves for time-temperature readings and for temperature fall along the soil box are not given for each experiment, since such a full treatment would render this paper unnecessarily bulky, and since such curves to be of practical benefit need to be given with an accuracy which can be best attained by plotting each set of curves from such data as that given in Table II to a larger scale than published curves

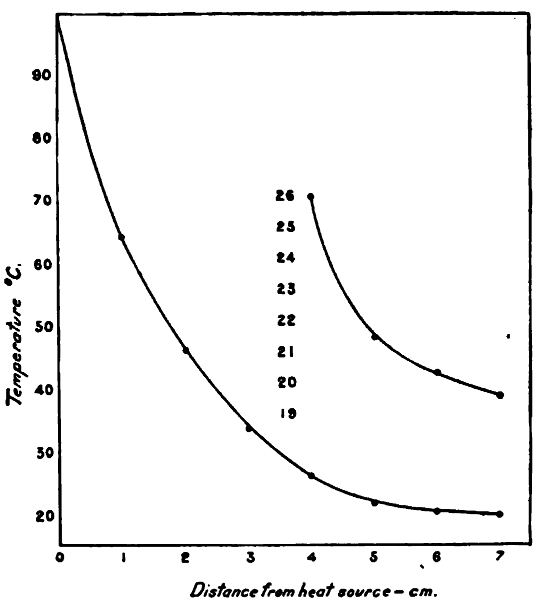

FIG. 12.—Temperature gradient for air-dry coarse quartz powder plotted to two different scales.

of this sort will admit. This method of treatment as shown in figures 10, 11, and 12 will be adhered to throughout this paper, consequently one complete analysis of the method used in calculating $\frac{d\theta}{dt}$, $\frac{d^2\theta}{dx^2}$, and the values for the absolute heat conductivity and diffusivity derived therefrom will suffice. In Table III there are also given a number of values for $\frac{d\theta}{dt}$ at 5 cm. from the heat source and under known conditions of packing and moisture content, but the auxiliary thermometers were not used to secure the temperature gradients in these experiments, so that the value $\frac{d^2\theta}{dx^2}$ is unknown. These values, however, serve as a check on the value $\frac{d\theta}{dt}$, and on the specific volume for the moisture contents given.

Talbe III.—*Summary of experimental and derived data.*

COARSE QUARTZ.

(1) Apparent specific volume, *V*.	(2) Moisture content on wet weight.	(3) Moisture content on dry weight.	(4) Effective specific heat *C*.[a]	(5) Rate of rise of temperature at 5 cm. from heat source (No. 5 thermometer). $\frac{d\theta}{dt}$	(6) Temperature at foot of No. 5 thermometer straight line rise.	(7) Time at foot of No. 5 thermometer straight line rise.	(8) Period required for rise of 6.3° C. at 5 cm. from heat source.	(9) Rate of change of temperature gradient at 5 cm. from heat source for dx = 0.5 cm. $\frac{d^2\theta}{dx^2}$	(10) (4) × (5) = calories per gram of soil per minute.	(11) (10) ÷ (1) = calories per cubic centimeter per minute.	(12) (11)÷(60) = calories per cubic centimeter per second.	(13) (12) ÷ (9) = calories per square centimeter per second per degree change in temperature gradient = *K* = $\frac{C}{V}\left(\frac{d\theta}{dt}\right)\div\left(\frac{d^2\theta}{dx^2}\right)$	(14) (5) ÷ (9) = diffusivity rate of rise of temperature at 5 cm. from heat source per degree change in temperature gradient. $\left(\frac{d\theta}{dt}\right)\div\left(\frac{d^2\theta}{dx^2}\right)$
Cc.	*Per cent*	*Per cent.*	*Calories.*	*°C. per minute.*	*°C.*	*Min. sec.*	*Min. sec.*	*°C. per cm. per cm.*					*°C. per minute.*
0.611	0.011	0.011	0.1901	0.320			35 00		0.0608	0.0995	0.00166		
.617	.015	.015	.1901	.329			32 35		.0625	.1013	.00169		
.601	.095	.095	.1908	.433	21.5	17 25	27 20	2.50	.0826	.1374	.00229	0.000917	0.173
.623	.095	.095	.1908	.333	26.4	23 45	29 45	2.40	.0750	.1203	.00205	.000854	.164
.750	.826	.833	.1967	.500					.0983	.1310	.00208		
.761	1.290	1.36	.2005	.565			17 40		.1133	.1488	.00248		
.753	1.610	1.64	.2030	.662			15 50		.1344	.1785	.00298		
.778	1.680	1.71	.2036	.646				1.60	.1313	.1688	.00281	.001756	.403
.771	2.110	2.16	.2071	.769	22.3	10 30	15 55	2.00	.1591	.2065	.00344	.001720	.385
.760	3.500	3.63	.2184	.701			14 20		.1531	.2014	.00336		
.739	3.840	3.99	.2211	.632					.1397	.1890	.00315		
.770	5.230	5.52	.2320	.960				2.00	.2225	.2890	.00482	.00241	.480
.748	6.320	6.75	.2412	.650			15 45		.1568	.2090	.00349		
.721	9.860	10.91	.2699	1.008	21.95	8 10	12 15	2.4	.2720	.3772	.00628	.002616	.420
.709	10.130	11.27	.2721	.537			17 48		.1461	.2060	.00343		
.535	20.260	26.70	.3514	.494	26.4	9 25	19 00	2.00	.1737	.3250	.00542	.00271	.247
.512	21.740	27.80	.3661	.294			28 15		.0782	.1526	.00254		
.535	24.050	31.70											
FINE QUARTZ FLOUR.													
1.130	0.0833	0.0833	0.1908	0.277	24.0	25 45	38 25	1.92	0.0529	0.0468	0.000781	0.000407	0.144
1.093	4.11	4.28	.2233	.712	23.4	9 25	16 00	2.52	.1589	.1454	.00242	.000960	.283
1.040	6.48	6.93	.2416	.704	25.7	10 40	15 35	2.40	.1845	.1775	.00297	.000124	.318
1.008	8.02	8.72	.2550	.758	25.2	9 35	15 00	1.92	.1937	.1922	.0032	.00167	.394
1.028	8.70	9.53	.2605	.790	24.7	10 05	15 20	2.48	.2057	.2001	.00333	.00134	.318

.965	9.84	10.92	.2697	.761	23.0	9 25	15 35	2.00	.2052	2127	.00354	.00177	.380
1.057	10.83	12.15	.2777										
1.030	14.31	16.70	.3059										
.972	16.42	19.67	.3230	.887	27.5	10 25	14 35	1.80	.2865	.3050	.00508	.00282	.493
.549	21.04	26.65	.3604	.625	27.0	9 25	16 10	1.28	.2452	.4100	.00683	.00534	.488
HUDSON RIVER SAND.													
0.738	0.256	0.257	0.1790	0.407	24.6	22 45	30 12	2.52	0.0729	0.0987	0.00165	0.000654	0.1613
1.058	4.31	4.50	.2124	.683	24.4	11 55	17 50	2.52	.1450	.1372	.0229	.00907	.271
1.026	9.55	10.55	.2555										
.900	15.34	18.12	.3032	1.170	24.8	10 12	13 00	2.20	.3550	.3950	.0659	.0299	.532
.541	[b] 23.52	30.76	.3705	.684	24.9	9 55	15 18	2.00	.2538	.4690	.0792	.0395	.342
PODUNK FINE SANDY LOAM.													
0.698	0.267	0.268	0.1850	0.358	24.3	21 10	32 10	2.00	0.0663	0.0950	0.001582	0.000792	0.179
.810	1.31	1.33	.1935	.508	23.0	20 10	25 35	2.56	.0985	.1215	.00203	.000792	.198
.926	2.11	2.14	.2000	.698	24.0	13 40	18 30	2.80	.1397	.1453	.00243	.000867	.249
1.000	2.76	2.83	.2053	.710	22.7	11 35	16 55	2.40	.1457	.1457	.00243	.001012	.290
1.085	6.19	6.601	.2334	1.007	24.2	9 55	13 45	2.88	.2352	.2165	.00361	.00125	.350
1.032	9.15	10.08	.2575	1.002	22.9	8 20	12 55	2.40	.2575	.2495	.00417	.001735	.417
.859	16.84	20.25	.3204	.994	23.8	12 00	15 05	2.40	.3185	.3710	.00619	.00258	.414
.525	21.22	26.93	.3562	.484	23.8	10 25	20 00	1.00	.1727	.3290	.00548	.00548	
LEONARDTOWN SILT LOAM.													
0.828	0.800	0.806	0.2374	0.444	24.7	20 45	31 30	2.4	0.1056	0.1275	0.00213	0.000886	0.1850
.878	2 083	2.127	.2455	.560	24.1	15 55	22 50	3.0	.1375	.1567	.00261	.000870	.1866
.865	3.450	3.580	.2563	.777	24.4	15 10	19 05	2.2	.1992	.2305	.00385	.001750	.3532
.931	4.470	4.690	.2374	.761	24.6	13 30	17 20	2.8	.2008	.2090	.00348	.001243	.2718
.924	8.240	8.980	.2929	.833	23.9	10 45	15 18	2.4	.2440	.2642	.00441	.001837	.3470
.878	9.620	10.650	.3035	.897	25.0	11 15	14 40	2.2	.2725	.3070	.00513	.002332	.408
1.002	10.367	11.570	.3065	.900	24.8	11 00	15 05	2.8	.2760	.2702	.00451	.001610	.3214
1.017	15.150	18.350	.3465	.948	24.0	11 15	14 40	2.6	.3287	.3231	.00538	.002070	.3646
.508	26.370	35.810											
.561	26.240	35.580											

[a] Specific heat of dry soil taken as 0.1900.

[b] Saturated with water.

TABLE III.—*Summary of experimental and derived data*—Continued.

MUCK SOIL.

(1) Apparent specific volume, V.	(2) Moisture content on wet weight	(3) Moisture content on dry weight.	(4) Effective specific heat C a	(5) Rate of rise of temperature at 5 cm. from heat source (No 5 thermometer). $\frac{d\theta}{dt}$	(6) Temperature at foot of No. 5 thermometer straight line rise.	(7) Time at foot of No. 5 thermometer straight line rise.	(8) Period required for rise of 6.3° C. at 5 cm. from heat source.	(9) Rate of change of temperature gradient at 5 cm from heat source for dx = 0.5 cm. $\frac{d^2\theta}{dx^2}$	(10) (4) × (5) = calories per gram of soil per minute	(11) (10) ÷ (1) = calories per cubic centimeter per minute.	(12) (11) ÷ (60) = calories per cubic centimeter per second.	(13) (12) ÷ (9) = calories per square centimeter per second per degree change in temperature gradient = $K = \frac{C}{V}\left(\frac{d\theta}{dt}\right) \div \left(\frac{d^2\theta}{dx^2}\right)$	(14) (5) ÷ (9) = diffusivity rate of rise of temperature at 5 cm. from heat source per degree change in temperature gradient. $\left(\frac{d\theta}{dt}\right) \div \left(\frac{d^2\theta}{dx^2}\right)$
Cc	*Per cent*	*Per cent*	*Calories.*	*°C. per minute.*	*°C*	*Min sec.*	*Min sec.*	*°C. per cm. per cm.*					*°C. per minute.*
0.895	3.78	3.93	0.1884	0.427	26.3	28 30	31 50	4.28	0.0804	0.0898	0.001495	0.000349	0.0999
1.250	18.67	22.95	.3140	.510	24.0	30 00	34 10	2.80	.1602	.1282	.002138	.000763	.1821
1.572	32.0	47.06	.4265	.530	24.0	29 40	35 25	3.20	.2260	.1437	.002395	.000748	.175
1.463	37.1	58.98	.4695	.485	28.9	21 00	27 20	2.40	.2275	.1550	.002595	.001081	.202
1.488	38.6	62.83	.4822	.516	29.7	20 15	25 40	2.60	.2475	.1673	.00277	.001066	.198
1.407	40.97	69.42	.5021	.395	22.7	27 55	35 15	2.72	.1984	.1410	.00235	.000864	.145
.809	[a] 54.3	119.2	.6145	.292	22.7	23 00	38 18	1.72	.1793	.2220	.00370	.00215	.170
.765	[a] 55.16	123.0	.6218	.274	23.0	27 00	42 25	2.24	.1704	.2230	.00371	.00166	.122
HAGERSTOWN LOAM.													
0.949	1.11	1.12	0.2004	0.397	29.0	19 35	28 50	2.00	0.796	0.0838	0.00140	0.000099	0.199
.602	32.45	48.06	.4538	.590	26.9	10 09	18 00	2.00	.268	.445	.00741	.00370	.295
GALVESTON CLAY.													
0.949	1.39	1.41	0.2207	0.388	29.2	24 40	34 00	2.6	0.0856	0.0902	0.00150	0.000577	0.1492
.654	40.31	67.55	.3283	.433	25.6	13 30	24 25	1.6	.2287	.3495	.00576	.00360	.2706
NO. 4 SAND.													
0.648	0.018	0.0198	0.1836	0.382	25.4	21 50	31 40	2.4	0.07015	0.1080	0.0018	0.00075	0.1591

Specific heat of dry Hagerstown soil 0.1914
Galveston soil .... .2097
No. 4 sand .... .1835

[a] Flows.

In Table III several columns of auxiliary data are given in addition to that required merely for the calculation of the heat conductivity and diffusivity. Column 1 contains the experimental value for the apparent specific volume at the moisture content given in column 2, while column 3 shows this same moisture content calculated to percentage on the dry weight of the soil, and column 4 gives the effective specific heat calculated from the moisture content in column 3, the specific heat of solid quartz being taken as 0.1900 and that of water as 1. Column 5 shows the rate of rise of the thermometer at 5 cm. from the heat source *per minute;* column 6 gives the temperature at which this rate of rise begins to be constant; and column 7 the *time*—from the application of the soil box to the source of heat—at which this rate of temperature rise sets in. Column 8 gives the period of time required for the temperature of the soil at 5 cm. from the heat source to rise 6.3° C., an interval of temperature chosen arbitrarily, but serving to compare the effect of moisture in soil upon the rate at which the soil heats up at a fixed distance from a constant-temperature heat source whose heat supply is infinite. Column 9 contains the graphically calculated values of $\frac{d^2\theta}{dx^2}$, obtained in each case by use of three sets of curves as shown in figures 10, 11, and 12, and given here for $\Delta x = 0.5$ cm. in every case. Column 10 shows the product of the effective specific heat (column 4) and the rate of temperature rise per minute; this product in column 10 is divided by the apparent specific volume (column 1) and the result given in column 11, which again is divided by 60, to reduce the time unit from minutes to seconds, and the result placed in column 12. This last column again is divided by $\frac{d^2\theta}{dx^2}$ as given in column 9 and the final value for K, the absolute heat conductivity obtained, as shown in column 13. Column 14 contains the diffusivity or rate at which the temperature rises under a unit temperature gradient. This is calculated by dividing the rate of rise of temperature at a distance of 5 cm. from the heat source by the rate of change of temperature gradient with distance from heat source, i. e. $\left(\frac{d\theta}{dt}\right) \div \frac{d^2\theta}{dx^2}$.

In figure 13 the apparent specific volume, the heat conductivity, and the diffusivity have been plotted as ordinates, and the moisture contents of the quartz as abscissas. The special scale for ordinates used for each curve is shown at the left for the heat conductivity and at the right for the diffusivity and specific volume. The specific volume curve shows an optimum water content at a point somewhere between 2 and 4 per cent of moisture on the wet weight. The diffusivity curve goes through a maximum value, but the maximum shows no direct relation to the optimum water content. This maximum diffusivity is due to the fact that a little water in the quartz affords contact between the grains and breaks down the air insulation, but as more and more water is added the heat capacity of the moist quartz is raised, and in consequence thereof the temperature rise, produced by a given quantity of heat, is necessarily lowered. The curve for heat conductivity rises regularly, and at the moisture contents studied approaches a maximum value. The last point taken (20.26 per cent of water on wet weight) was for quartz saturated with water; at higher moisture contents the heat conductivity would gradually fall to the heat conductivity of water. Consider now the time required for the temperature at a distance of 5 cm. from the heat source to rise 6.3° C., as shown in column 8. For the air-dry quartz it varies from 35 minutes to 27 minutes 20 seconds, depending on the moisture

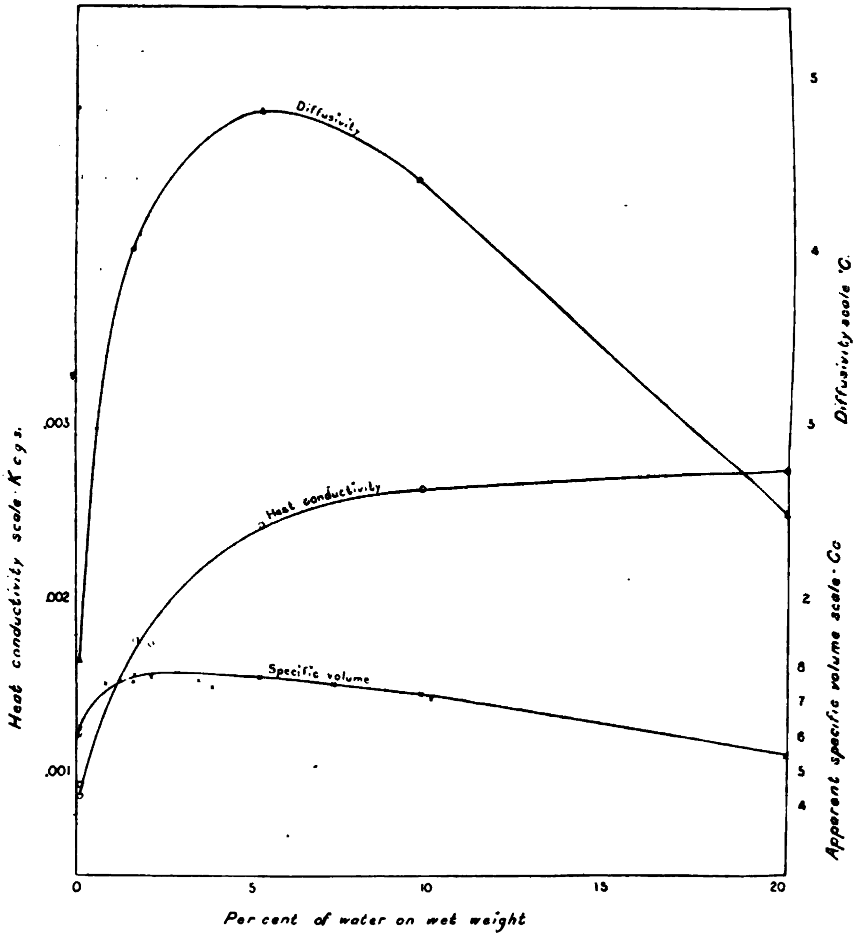

FIG. 13.—Effect of moisture upon the apparent specific volume, heat conductivity, and diffusivity of coarse quartz powder.

content and packing. Addition of 1.2 per cent of moisture reduces this time to 17 minutes 40 seconds, some 50 per cent; but further addition of water only slightly decreases this time, which is again increased as the quartz becomes saturated with water. From these last observations it is evident that the determination of the time required by any *one point* in the soil to rise through a stated temperature interval can not be taken as a measure of the ability of the soil to conduct heat.

SOURCES OF ERROR.

Effect of working in the "unsteady state."—The necessity for taking temperature-time curves in the unsteady state, to avoid evaporation of soil moisture from the layer in which it is desired to measure the heat conductivity, introduces the factor $\frac{d^2\theta}{dx^2}$, the acceleration of the temperature with respect to distance from the heat source. And the evaluation of this factor $\frac{d^2\theta}{dx^2}$ requires the use of second differences for temperature data, which data are of such a nature that these second differences may lie very close in value to the error of experiment.

Two methods of calculating $\frac{d^2\theta}{dx^2}$ are available: (*a*) The graphical method, which has been described above, consists in measuring off a value of $\Delta\theta$ and of Δx on the temperature-distance curve given in figure 12 and taking this ratio $\frac{\Delta\theta}{\Delta x}$. If we do this at two points on the curve at a distance Δx from each other and then subtract these two ratios $\frac{\Delta\theta_1}{\Delta x_1}$ and $\frac{\Delta\theta_2}{\Delta x_2}$, and divide the remainder by Δx, we have performed the operation indicated by the symbol $\frac{d^2\theta}{dx^2}$ and get its value at once. The difficulty is that different magnitudes of Δx give different values of $\frac{d^2\theta}{dx^2}$, and the choice of the proper Δx must be made so that it is considerably greater than the experimental error and still is not so large as to cover too great a length of the curve, θ, x, whose direction is rapidly changing. In this paper Δx has been taken as 0.5 cm. and the various values of $\frac{d^2\theta}{dx^2}$ worked out upon that basis.

(*b*) The analytical method of evaluating $\frac{d^2\theta}{dx^2}$ consists in determining the empirical constants of the curve, θ, x, from the observed data.

The advantage in this method lies in that it enables us to use rigid differentiation, the $\Delta\theta$ and Δx being carried to the limit and becoming $d\theta$ and dx, infinitesimally small. The disadvantage of the method is the immense quantity of detailed computation involved. On this account we have used the less exact graphical method of deriving $\frac{d^2\theta}{dx^2}$. Later, if it is thought that the other experimental errors which limit the accuracy of this work warrant it, this analytical method of evaluating $\frac{d^2\theta}{dx^2}$ may be taken up.

Spacing of thermometers.—The thermometers were placed with the central diameters 1 cm. apart. A deviation of 0.05 mm. from the correct position would mean an error of 5 per cent. Consequently the values given throughout this paper may be 5 per cent high or low from this source of error alone.

Dimensions of thermometers.—The diameters of the thermometer bulbs varied as much as 1 mm. from the average value 5 mm. This error might add to or subtract from the error of placement (No. 2), depending upon the signs (+ or −) of each error involved.

Reading of thermometers.—The error due to slow response of the mercury thread in the thermometer to change in temperature is a much more serious error factor than the personal error involved in taking the position of the mercury thread with a hand lens. The position of the mercury meniscus may be determined certainly within a fifth of a degree and very nearly to a tenth with the thermometers used. This slow response of the mercury to temperature change was partially overcome by tapping each thermometer before reading it: but where temperature-time readings are taken, the general trend of the curve is all that can be hoped for, even using a Beckmann differential thermometer graduated to 0.01° C. and a 0.2 second stop watch.

Reading of stop watch.—The time was read to seconds on the stop watch, but since the same observer reads the mercury of the thermometer and the watch, there is a lack of coordination between temperature and time in the readings which amounts to an error of from one-half to one second. This error together with the sticking of the mercury thread prevents the use of thermometers of a fine graduation.

Determination of moisture.—The moisture determinations were made using samples of the soil from the *same batch* as that used to fill the soil box; the samples were taken at the time when the soil box was being filled from the mechanical packer, and consequently were in the same state as the soil in the soil box. In several cases the soil remaining in the box after a heat conductivity experiment had been finished was tested and its moisture content found to be nearly the same as at first *in the part of the soil beyond the thermometer 5 cm. from the heat source.* Distillation of moisture of course takes place near the heat source, but this does not extend in a marked way much beyond 3 cm. out from the heat source. The lack of an accurate soil hygrometer prevents exact determination of this distillation phenomenon. Finally it may be stated that the moisture-content value is the least subject to error of any of the factors in this research. The experimental errors involved in its determination are so slight as to have no appreciable influence upon the effective specific heat of the soil as calculated from the moisture content.

Apparent specific volume.—This factor in the problem is very difficult to control. The packing of the soil at the bottom of the soil box is closer than at the top, owing to the difference in height of fall from the sieve of the mechanical packer (fig. 9) and to the weight of the soil. This effect is obvious from theoretical considerations, and was experimentally demonstrated by volume-weight determinations made under the conditions of this experimental investigation. Consequently the apparent specific volume was determined as an average value from top to bottom of the soil box by allowing the soil, in the same condition as to moisture as that in the box, to fall from the mechanical packer into a deep, wide crystallizing dish sufficiently large to represent the volume conditions obtaining in the soil box. A number of duplicate volume-weight determinations showed the precision of this method so far as an individual batch of soil was concerned. It can not be too strongly emphasized, however, that the same soil with practically the same moisture content gives considerable variation in the apparent specific volume, owing to differences in the state of aggregation of the soil grains, which arise probably from otherwise undetected variations in the distribution of moisture. On this account, then, it is not surprising if duplicate determinations of the heat conductivity and diffusivity of soils show a considerable variation. However, the results obtained in this investigation show much greater regularity than might be expected.

The specific heat.—The determination of the specific heat of each soil in oven-dry condition was made by heating 100 grams of the sample to nearly 100° C. in a steam bath and then quickly stirring the hot soil into the water in a calorimeter.[a] The rise in temperature was taken on a Beckmann differential thermometer graduated to 0.01° C. and the customary calculation made. A separate experiment, using the same quantities of water and of soil at the same temperature (about 25° C.), gave the temperature effect due to the simple wetting of the dry soil. This effect was allowed for in all the specific heat determinations made in this investigation.

Table IV shows the magnitude of this effect for several soils.

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[a] Compare Ulrich, Forsch. Geb. Agr. Phys. **17**, 1 (1894).

TABLE IV.—*The heat evolved by wetting certain soils, dried at 110° C.*

Weight of soil.	Water equivalent of calorimeter system.	Temperature rise.	Specific heat of dry soil (corrected).	Water equivalent of soil.	Total water equivalent of system.	Heat evolved by wetting soil.	Heat evolved per gram of soil.	Temperature of observation.	Name of soil.
Grams.	*Grams.*	° *C.*		*Grams.*	*Grams.*	*Calories.*	*Calories per gram.*	° *C.*	
100	515.3	0.070	0.1848	18.48	533.8	37.4	0.374	24	Norfolk sand.
100	515.3	.060	....	18.48	....	32	.320	....	
100	511.87	1.360	.1566	15.66	527.53	716	7.16	24.2	Muck soil, 25 per cent organic matter.
100	515.3	1.190	.1566	15.66	530.96	632	6.32	25.3	Do.
100	515.3	1.085	.1566	15.66	530.96	576	5.76	24.8	
100	532.87	.662	.2097	20.97	553.84	366	3.66	24.5	Galveston clay.
100	515.3	.730	.2097	20.97	536.27	391	3.91	25.2	Do.
100	515.3	.205	.1914	19.14	534.44	109.5	1.095	24.3	Hagerstown loam.
100	515.3	.210	.1914	19.14	534.44	112.2	1.122	24.4	Do.
100	515.3	.155	.1944	19.44	534.74	83	.83	24.3	Leonardtown silt loam.
100	515.3	.155	.1944	19.44	534.74	83	.83	26	
100	515.3	.050	.1828	18.28	533.58	26.7	.267	25	Podunk fine sandy loam.
100	515.3	.025	.1828	18.28	533.58	13.3	.133	24.5	Do.
100	515.3	.030	[a] .1900	19	534.3	16.02	.160	24.6	Large quartz grains.
100	515.3	.026	[a] .1900	19	534.3	13.88	.139	25.6	Do.
100	515.3	.080	[a] .1900	19	534.3	42.7	.427	24.2	Fine quartz flour.
100	515.3	.057	.1900	19	534.3	34.5	.345	24.5	
100	515.3	.045	.1769	17.69	533	25	.250	23.5	Hudson River sand.
100	515.3	.020	.1769	17.69	533	10.7	.107	23.7	
100	515.3	.080	.1799	17.99	533.29	42.7	.427	24.5	No. 4 sand. Soil separate.
100	515.3	.077	.1799	17.99	533.29	41.1	.411	25.4	

[a] Assumed from data in Landolt & Börnstein.

The effect of size of soil grain is well shown by the two grades of quartz flour, the coarse evolved 0.160 and 0.139 calories per gram, while the fine quartz, which is nearly all a silt, evolved 0.427 and 0.345 calories per gram. The heat effect of wetting grades down from 7.16, 6.32, and 5.76 calories per gram for a muck soil containing 25 per cent of organic matter, to as low as 0.25 and 0.107 calories per gram for a Hudson River sand.[a] The influence of this heat of wetting factor in specific heat determinations may be very great. Thus the ordinary muck soil gives an apparent specific heat of 0.2400, but when correction for the heat of wetting is made the true value of the specific heat is seen to be 0.1566, an error of over 33 per cent.

In calculating the effective specific heat of a soil at any one moisture content, one simply adds the heat capacity of the water to that of the dry soil.

Contact of soil box with source of heat.—There is no doubt that perfect contact between the copper end of the soil box and the brass end of the heat source was not secured. However, the temperature gradient and rate of rise of the soil thermometers furnish the necessary data for the purpose in hand, so that the exact temperature of the soil at 0.2 to 0.6 cm. from the heat source makes no difference in the result obtained *for the heat conductivity* and *diffusivity*, while it certainly does make a great difference in the quantity of heat which passes along into the soil box.

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[a] Compare Mitscherlich, Landw. Jahrb. **30**, 361 (1901); **31**, 577 (1902); also Jour. f. Landw. (1900), p. 71.

Variation in the temperature of the heat source.—The variations in the temperature of the heat source were not greater than 0.2° C. and usually were not of sufficient duration to show in the rate of rise of the soil thermometers. The error from this source is negligible.

Loss of heat by radiation.—The soil box was well insulated and the thermometers in the central diameter were each protected by some 4 cm. of soil from the influence of the sides of the box. Consequently the radiation effect may be neglected.

FINE QUARTZ.

The fundamental data for the temperature-time curves were taken, using a fine quartz flour at various moisture contents, the method of procedure being exactly as described above for the coarse quartz powder. Table V gives the mechanical analysis of this fine quartz flour, which is seen to be 80.5 per cent silt.

TABLE V.—*Mechanical analysis of fine quartz flour.*

Diameter of grain.	Conventional names.	Per cent.[a]
Millimeters.		
2-1	Fine gravel	0.00
1-0.5	Coarse sand	1.01
0.5-0.25	Medium sand	.09
.25 -0.1	Fine sand	.16
.1 -.05	Very fine sand	8.00
.05 -.005	Silt	80.47
.005-0.0	Clay	10.84
Total		99.57

[a] Mean of ten samples.

The values of $\frac{d\theta}{dt}$ and $\frac{d^2\theta}{dx^2}$ were derived for each moisture content by the method described in detail for coarse quartz. These values, $\frac{d\theta}{dt}$ and $\frac{d^2\theta}{dx^2}$ are assembled in Table III (p. 26), together with the respective moisture contents and apparent specific volumes as determined experimentally for each of the experiments. In addition to the data summarized in Table III, a more extended series of experiments showing the dependence of apparent specific volume upon moisture content is given for fine quartz flour in Table VI.

The heat conductivity, K, the diffusivity, k, and the apparent specific volume, V, are each plotted in figure 14 as a function of the moisture content. The abscissas are per cents of moisture reckoned on the wet weight of quartz, and the ordinates are K, k, and V as shown by their respective scales in the right and left hand margins of figure 14.

From these three curves it appears that the heat conductivity rises in a fairly regular manner with increase in moisture content.

TABLE VI.—*Specific volume of fine quartz flour at various moisture contents.*

Moisture content on wet weight.	Specific volume.	Moisture content on wet weight.	Specific volume.
Per cent.	*C. c.*	*Per cent.*	*C. c.*
0.0833	1.130	9.84	0.965
.0833	1.151	10.22	1.110
.300	.927	10.4	.858
1.32	.947	10.83	1.057
2.97	.985	10.96	1.087
4.11	1.093	11.37	1.072
4.68	1.039	14.31	1.030
5.82	1.021	15.15	.911
6.48	1.040	16.42	.972
6.54	.992	17.78	.998
7.91	1.136	21.7	.683
8.02	1.008	22.68	.527
8.70	1.028	21.04	.549
8.80	1.050		

The influence upon the heat conductivity of the change in apparent specific volume is to lower the heat conductivity as the quartz assumes a more open structure in the neighborhood of the optimum water content (9 to 12 per cent on the wet weight). This relation is obscured by the difficulty experienced in securing uniform packing at each moisture content, so that the heat conductivity and diffusivity shown by lines which pass through actual experimental points are probably not so truly representative of the normal trend of the respective curves as the black-line curves drawn through the average of the points. It must be remembered, too, that error in the determination of $\frac{d^2\theta}{dx^2}$ in these places may be partly the cause of the departure of the value of K or k from the average curve. The apparent specific volume curve shows that a very dry, fine powder occupies a greater volume than when very slightly moistened. And in this case the greatest volume and lowest heat conductivity and diffusivity are shown by the air-dried quartz, which held only 0.083 per cent of water on the wet weight.

Comparing the coarse quartz, figure 13, with the fine quartz, figure 14, it is evident that the dry, fine quartz conducts heat much more poorly than the dry, coarse quartz in the ratio of about 4 to 8.7, and the diffusivities are as 1.44 for fine quartz to 1.65 for coarse quartz. At higher moisture contents this relation is maintained, the coarse quartz increasing more rapidly in its heat conductivity as water is added than does the fine quartz. But as the saturation point of the powders for water is approached the heat conductivity of the fine quartz becomes greater than that of the coarse quartz until it is nearly twice its value.

The apparent specific volume of the coarse quartz lies below that of the fine quartz at all moisture contents.

The diffusivity of fine quartz shows only a slight tendency to pass through a maximum as moisture increases, whereas in the case of the coarse quartz this maximum is pronounced. It may be that with a greater quantity of water in the quartz this diffusivity will be less, and thus show a real maximum at 16 per cent of water, where now it is merely indicated. The last diffusivity measurement was made using quartz flour containing sufficient water to make a batter which poured very easily, so further experiments have to meet the difficulty that the quartz flour will settle from suspension during the measurements of heat conductivity and diffusivity, thus masking the true values.

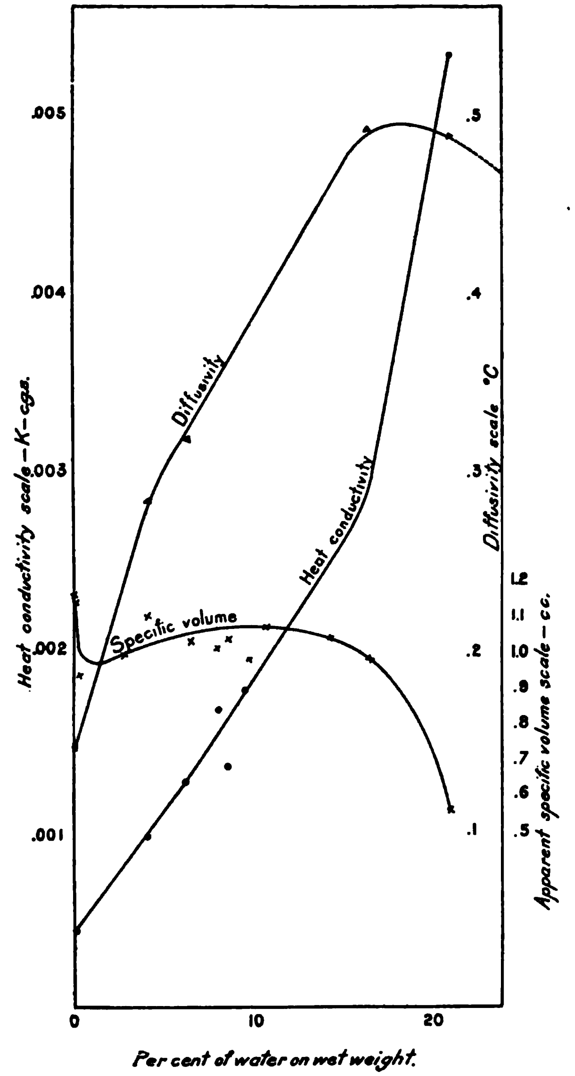

FIG. 14.—Curves for fine quartz powder similar to those in figure 13.

HUDSON RIVER SAND.

The heat conductivity and diffusivity of a Hudson River sand[a] were determined in the same manner as for the quartz powders. The values $\frac{d\theta}{dt}$ and $\frac{d^2\theta}{dx^2}$ together with the values of the apparent specific volume and moisture content are assembled in Table III (p. 27) for four different moisture contents, and in this same table are given the calculated heat conductivity and diffusivity. A mechanical analysis of this soil is shown in Table VII.

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[a] Kindly furnished by Brig. Gen. C. W. Raymond, U. S. A., retired, New York City.

TABLE VII.—*Mechanical analysis of Hudson River sand.*

Diameter of grain.	Conventional name.	Per cent.
Millimeters.		
2 -1	Fine gravel	0.1
1 -0.5	Coarse sand	0.5
0.5 - .25	Medium sand	1.3
.25 - .1	Fine sand	69.7
.1 - .05	Very fine sand	19.4
.05 - .005	Silt	7.6
.005- .0	Clay	1.5

Figure 15 shows graphically the variation of the heat conductivity, diffusivity, and apparent specific volume as the moisture content of the soil increases. All the curves for Hudson River sand show the same general form as those for coarse quartz in figure 13. The heat conductivity of the air-dry Hudson River sand is less than that of the coarse quartz and greater than that of the fine quartz flour. The highest value of the heat conductivity shown by Hudson River sand (in saturated condition) is below that of fine quartz flour and above that of coarse quartz. The maximum value of the diffusivity is, however, practically the same for each of these three soils; it comes at 16 per cent of moisture for fine quartz; at about 15.5 per cent for Hudson River sand; and at about 15.5 per cent for coarse quartz. It is possible, however, that this maximum diffusivity for Hudson River sand may be found at a lower moisture content when more experimental points are obtained; the value of the maximum, too, might be slightly higher.

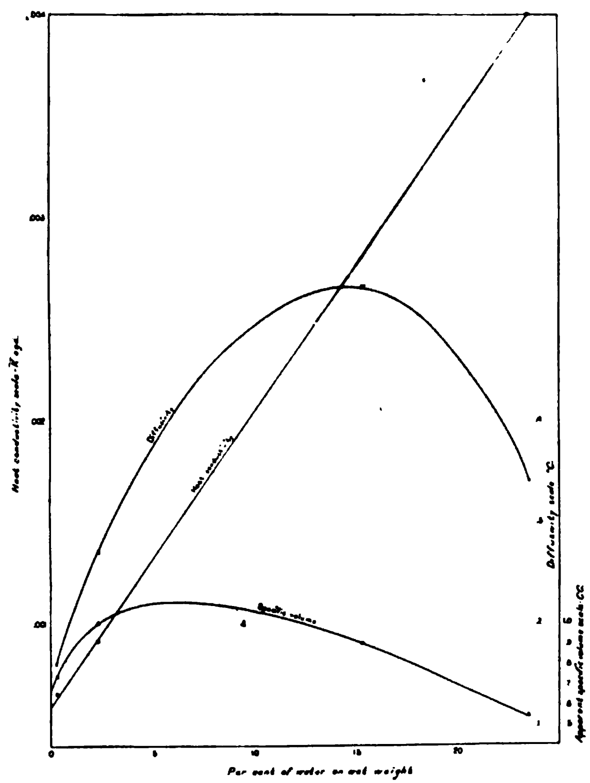

FIG. 15.—Curves for Hudson River sand similar to those in figure 13.

PODUNK FINE SANDY LOAM.

The mechanical analysis of Podunk fine sandy loam is given in Table VIII; the values for $\frac{d\theta}{dt}$ and $\frac{d^2\theta}{dx^2}$ are found in Table III (p. 26) which also contains the apparent specific volume, moisture content, heat conductivity, and diffusivity. These values are obtained as shown above for coarse quartz.

TABLE VIII.—*Mechanical analysis of Podunk fine sandy loam soil.*

Diameter of grain.	Conventional name.	Per cent.
Millimeters.		
2 -1	Fine gravel	0.0
1 -0.5	Coarse sand	1.7
0.5 - .25	Medium sand	3.0
.25 - .1	Fine sand	47.4
.1 - .05	Very fine sand	38.6
.05 - .005	Silt	7.5
.005- .0	Clay	1.8
Total		100.0

Figure 16 shows the variation of the heat conductivity, diffusivity, and apparent specific volume with increasing moisture content for this soil. The heat conductivity curve here is very regular, and like that in figure 14 for fine quartz is concave, whereas the heat conductivity curve in figure 13 for coarse quartz is markedly convex and that for Hudson River sand, figure 15, is very slightly convex. The regularity of both the heat conductivity and diffusivity curves in figure 16 suggests that the wide departure of several points in figures 14 and 15 from the general trend of their respective curves is due to error. It is seen further that the heat conductivity and diffusivity of the air-dry Podunk soil are practically the same as those of the air-dry coarse quartz, both being higher than for the air-dry fine quartz (fig. 14). The heat conductivity of the Podunk soil increases more slowly with increasing water content than does the heat conductivity of fine quartz flour, but reaches a slightly higher final value than that of the fine quartz when both soils are in a saturated condition. The diffusivity curve for Podunk soil is similar to that for fine quartz.

LEONARDTOWN SILT LOAM.

The heat conductivity and diffusivity of Leonardtown silt loam at eight different moisture contents were determined in the same manner as for the preceding soils. The values of $\frac{d\theta}{dt}$ and $\frac{d^2\theta}{dx^2}$ are given in Table III (p. 27), together with the apparent specific volume, moisture content, heat conductivity, and diffusivity. The mechanical analysis of the soil is given in Table IX.

TABLE IX.—*Mechanical analysis of Leonardtown silt loam.*

Diameter of grain.	Conventional name.	Per cent.
Millimeters.		
2 -1	Fine gravel	1
1 -0.5	Coarse sand	2
0.5 - .25	Medium sand	3
.25 - .1	Fine sand	7
.1 - .05	Very fine sand	12
.05 - .005	Silt	58
.005- .0	Clay	15

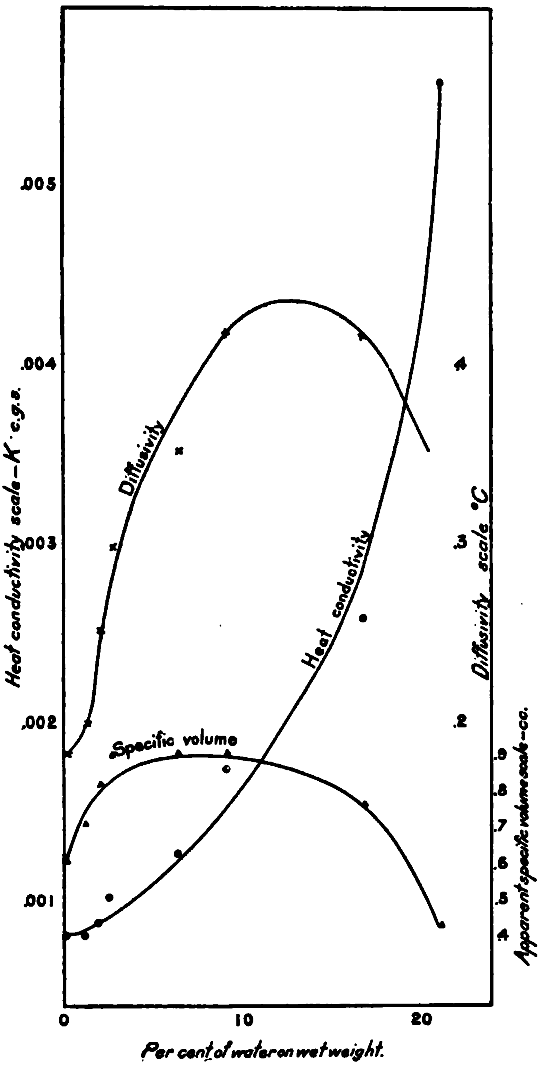

FIG. 16.—Curves for Podunk fine sandy loam similar to those in figure 13.

Figure 17 shows the variation of the heat conductivity, diffusivity, and apparent specific volume with increase in moisture content. Air-dry Leonardtown soil shows about the same heat conductivity as the coarse quartz (fig. 13), Hudson River sand (fig. 15), and Podunk soil (fig. 16). As the moisture content increases the heat conductivity of the Leonardtown soil rises a little faster than that of the Podunk soil or that of the fine quartz flour (fig. 14).

MUCK SOIL.

The experimental and calculated values used in deriving the heat conductivity and diffusivity of a muck soil containing 25 per cent of organic matter are given in Table III (p. 28), the experimental and analytical procedure being the same as used for the soils already discussed.

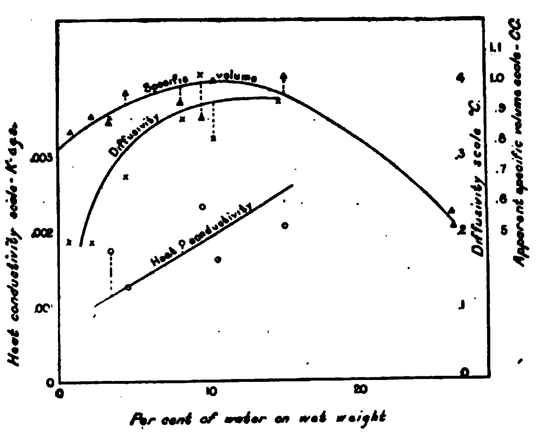

FIG. 17.—Curves for Leonardtown silt loam similar to those in figure 13.

Figure 18 shows graphically the variation of the apparent specific volume, heat conductivity, and diffusivity of this muck soil with increase in moisture content. The absolute values of both the heat conductivity and diffusivity are in general lower than for the soils already treated. The great departure of some experimental values shown in this figure from the general trend is due to the difficulty of securing even distribution of moisture. The apparent specific volume curve is fairly regular, and where single values lie off the curve, the effect of this departure upon the heat conductivity would produce neither the magnitude of effect nor the direction of effect actually observed in the heat conductivity and diffusivity. Consequently, the irregularity in these last is probably due largely to uneven distribution of moisture. It must be remembered, too, that the graphical calcu-

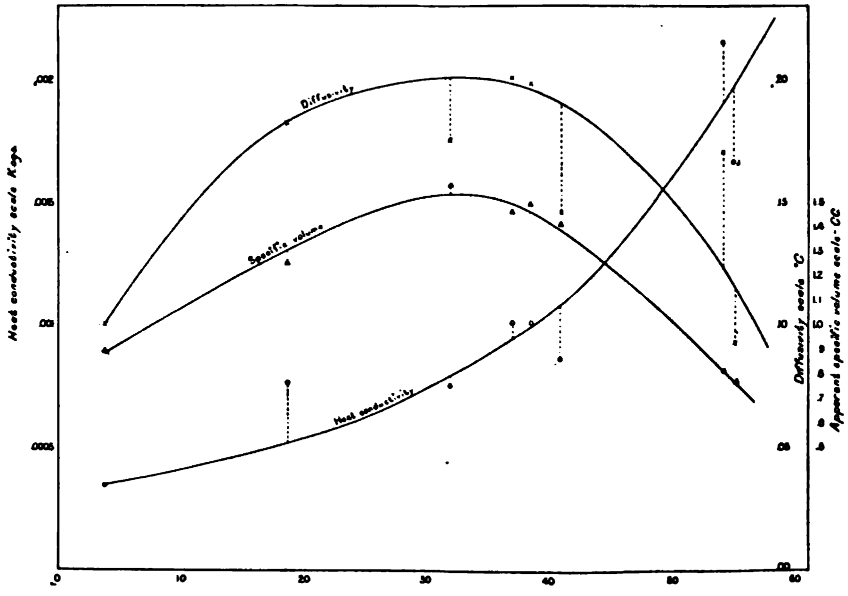

FIG. 18.—Curves for muck soil similar to those in figure 13.

lation of $\frac{d^2\theta}{dx^2}$ may well produce such variations. The pronounced concavity of the heat conductivity curve and the convexity of the diffusivity curve are worthy of note. This question will be taken up under the general discussion of the results obtained in this investigation.

HAGERSTOWN LOAM, GALVESTON CLAY, AND NO. 4 SAND.

A summary of the experimental and derived data for the Hagerstown loam, Galveston clay, and No. 4 sand is contained in Table III (p. 28). The mechanical analyses of the two soils proper are given in Table X. No. 4 sand is an average sample of the fine sand from many different soils of the United States. This sample was obtained by mixing the No. 4 fractions of soil obtained in the regular routine mechanical analysis of a large number of soils. For the Hagerstown and Galveston clay soils one heat conductivity determination was made in an air-dry and one in saturated condition. These values compare very well with each other and with the values given for the soils considered above. The high value of the heat conductivity of the dry No. 4 sand is due to the close packing of its particles, evidenced by its low apparent specific volume. The experimental procedure and calculations were the same for these three soils as for the six soils given above.

TABLE X.—*Mechanical analyses of Hagerstown loam and Galveston clay soils.*

Diameter of grain.	Conventional name.	Hagerstown loam.	Galveston clay.
Millimeters.		*Per cent.*	*Per cent.*
2 -1	Fine gravel	0.9	0.7
1 -0.5	Coarse sand	3.0	1.5
0.5 - .25	Medium sand	2.1	0.4
.25 - .1	Fine sand	6.5	7.0
.1 - .05	Very fine sand	13.9	28.9
.05 - .005	Silt	54.3	30.1
.005- .0	Clay	19.1	31.0
Total		99.8	99.6

TABLE XI.—*Fundamental data for determination of heat conductivity and diffusivity.*

[Name of soil: Norfolk sand.]

RATE OF RISE OF TEMPERATURE IN SOIL AT DIFFERENT DISTANCES FROM A STEADY SOURCE OF HEAT.

5 cm. from heat source.			10 cm. from heat source.			15 cm. from heat source.			20 cm. from heat source.			25 cm. from heat source.			30 cm. from heat source.		
Time.		Temp.	Time.		Temp.	Time.		Temp.	Time.		Temp.	Time.		Temp.	Time.		Temp.
min.	*sec.*	*° C.*	*min.*	*sec.*	*° C.*	*min.*	*sec.*	*° C.*	*min.*	*sec.*	*° C.*	*min.*	*sec.*	*° C.*	*min.*	*sec.*	*° C.*
0	0	20.5	0	0	20.3	0	0	20.4	0	0	20.5	0	0	20.4	0	0	20.4
7	0	20.7	12	30	20.4	15	30	20.6	21	30	20.9	22	0	20.7	22	30	20.7
12	0	20.9	20	30	20.7	26	30	21.0	35	0	21.4	31	30	21.0	32	0	21.0
15	45	21.2	26	30	21.0	38	30	21.7	44	15	21.9	39	10	21.2	45	0	21.3
23	15	22.3	38	0	21.8	49	30	22.3	52	30	22.2	48	10	21.6	53	30	21.8
25	45	23.0	47	0	22.5	63	0	23.1	67	30	23.0	53	0	21.9	60	0	22.0
28	10	23.5	57	15	23.6	85	45	24.8	86	15	24.0	59	30	22.1	87	15	22.8
30	0	24.0	66	20	24.7	97	30	25.6	95	15	24.5	68	0	22.4	96	0	23.0
34	0	25.0	85	20	26.8	111	0	26.5				87	0	23.3	107	0	23.4
37	30	26.0	93	15	27.8	124	30	27.5	118	30	25.5	98	30	23.8	119	10	23.8
40	0	26.9	100	15	28.6	141	30	28.5	142	0	26.6	112	5	24.2	134	15	24.1
43	0	27.7	110	45	29.7	173	0	30.1	173	15	27.9	125	15	24.8	148	45	24.5
46	30	28.7	128	30	31.4	193	0	31.2	193	30	28.8	143	0	25.3	174	0	25.2
48	50	29.4	135	40	32.0	221	30	32.5	222	0	29.8	173	40	26.4	205	0	26.0
54	0	30.9	147	30	33.0	240	45	33.4	252	30	30.9	184	45	26.8	222	45	26.5
57	0	31.7	155	0	33.6	267	20	34.4	290	15	31.9	211	0	27.6	242	0	27.0
62	0	33.1	172	30	34.9	290	0	35.0	324	40	32.5	241	45	28.5	268	30	27.8
66	0	34.0	183	15	35.6	324	30	35.7				253	15	28.8	312	30	28.3
70	0	35.0	203	0	36.9							290	40	29.8	325	30	28.4
85	0	38.3	220	30	37.8							312	0	30.0			
91	0	39.5	240	15	38.7							325	0	30.2			
96	30	40.4	251	45	39.2												
105	20	41.9	289	15	40.5												
113	0	43.0	324	0	41.2												
122	15	44.3															
140	30	46.3															
154	30	47.7															
172	0	49.2															
192	0	50.6															
208	30	51.6															
231	0	52.8															
251	30	53.5															
289	0	54.6															
324	0	55.1															

Temperature of heat source 100°-99° C.
Heat applied at 0′ 0″.
Apparent specific volume 0.750.
Moisture content, wet weight, 0.1 per cent.

NORFOLK SAND. THERMOMETERS PLACED 5 CENTIMETERS APART.

Table XI contains the experimental observations for the temperature-time curves of air-dry Norfolk sand, the thermometers being

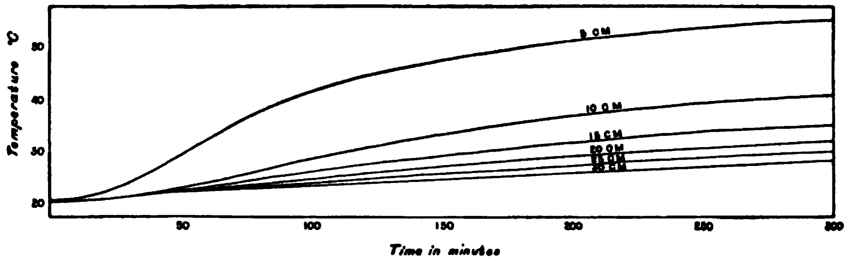

FIG. 19.—Temperature-time curves for air-dry Norfolk sand.

5 cm. apart. The mechanical analysis of this soil is given in Table XII. Figure 19 shows the basal temperature-time curve for the thermometers placed at 5, 10, 15, 20, 25, and 30 cm., respectively,

from the heat source and in the central diameter of the soil box. Figure 20 gives the temperature-time curve for the thermometer at 20 cm. from the heat source, but on a larger scale than in figure 19, in order to determine $\frac{d\theta}{dt}$, which is found to be 0.0487° C. per minute. This rate of rise begins at 27 minutes after applying the soil box to the heat source, consequently a cross section of the curves in figure 19 should be taken at this time in order to find the value of $\frac{d^2\theta}{dx^2}$. But the temperature gradient is so flat at this distance from the heat source that $\frac{d\theta}{dx}$, the first differential, can not be measured accurately with thermometers reading only to 0.1° C., much less a second differential $\frac{d^2\theta}{dx^2}$. This makes clear the necessity of inserting thermometers at short distances from each other, and using a steep temperature fall, if the value $\frac{d^2\theta}{dx^2}$ is to be obtained even very roughly. As a makeshift, the temperature gradient at 50 minutes was taken from the data given in Table XI, plotted in figure 21 and a value of $\frac{d^2\theta}{dx^2}$ found graphically as 0.0325° C. Using the formula

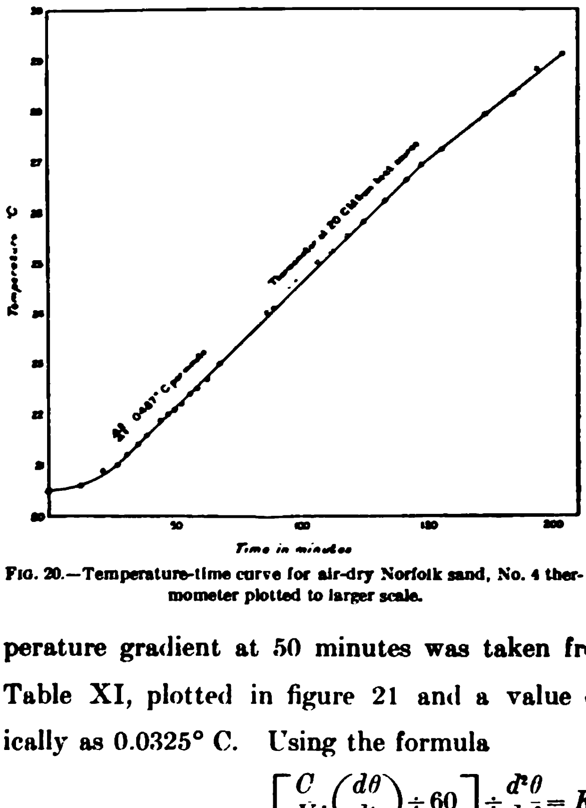

FIG. 20.—Temperature-time curve for air-dry Norfolk sand, No. 4 thermometer plotted to larger scale.

$$\left[\frac{C}{V}\cdot\left(\frac{d\theta}{dt}\right)\div 60\right]\div\frac{d^2\theta}{dx^2}=K$$

it is seen that $K=0.00615$, since V, the apparent specific volume is 0.750; $C=0.1848$, the effective specific heat, and $\frac{d\theta}{dt}=0.0487°$ C. per minute. This value of $\frac{d^2\theta}{dx^2}$ at 50 minutes is obtained using 2.5 cm. as the value of Δx. A similar gradient taken at 75 minutes after the soil box is applied to the heat source gives a value for $\frac{d^2\theta}{dx^2}$ of

0.0096° C. Now the rate of rise of thermometer No. 4 at 75 minutes is the same as at 50 minutes, consequently this value 0.0096 for $\frac{d^2\theta}{dx^2}$ when introduced into the above equation gives a value for the heat conductivity over three times greater ($K=0.0211$) than that obtained using the $\frac{d^2\theta}{dx^2}$ obtained from the temperature gradient at 50 minutes.

This large error emphasizes the necessity of taking the temperature gradient, and the rate of rise of the chosen thermometer (No. 4 in this case) at the time when the rate of rise of temperature just begins to be constant. When this is done a comparison of the heat conductivity values shows regularity which otherwise disappears. It is clear from the values of the heat conductivity of the various air-dry soils given above that both of these values just given ($K=0.00615$ and $K=0.0211$) for air-dry Norfolk sand are very much too high. The lower values given in the work on the foregoing nine soils, moreover, are remarkably close to those obtained by other investigators, as will be shown farther on.

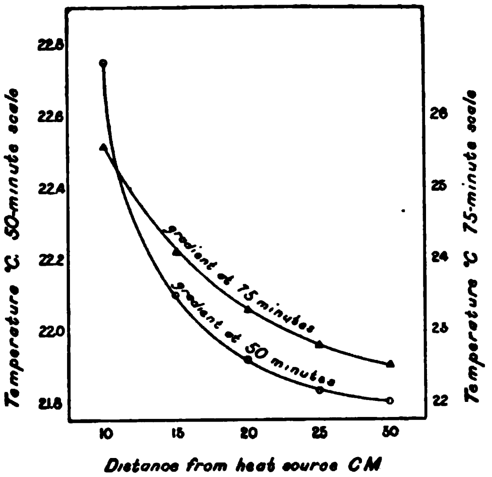

FIG. 21.—Temperature gradients for air-dry Norfolk sand at 50 minutes and 75 minutes.

TABLE XII.—*Mechanical analysis of Norfolk sand*

Diameter of grain.	Conventional name.	Per cent.
Millimeters.		
2 -1	Fine gravel	0.2
1 -0.5	Coarse sand	6.3
0.5 - .25	Medium sand	22.2
.25 - .1	Fine sand	63.7
.1 - .05	Very fine sand	4.1
.05 - .005	Silt	1.0
.005- .0	Clay	1.8

CARBORUNDUM—EFFECT OF SIZE OF GRAIN UPON HEAT CONDUCTIVITY AND DIFFUSIVITY.

Table XIII contains the values $\frac{d\theta}{dt}$ and $\frac{d^2\theta}{dx^2}$ for nine different grades of carborundum powder, whose respective moisture contents, apparent specific volumes, average diameter of grain, and effective specific heats are given under appropriate headings, as well as the calculated values of the heat conductivity and diffusivity. In figure 22 the apparent specific volume, heat conductivity, and diffusivity of the carborundum powders are plotted as a function of the average diameter of the grain of each powder. Diameters are taken as abscissas; and as ordinates, the heat conductivity (to the left), the diffusivity (to the right, above), and the apparent specific volume (to the right, below).

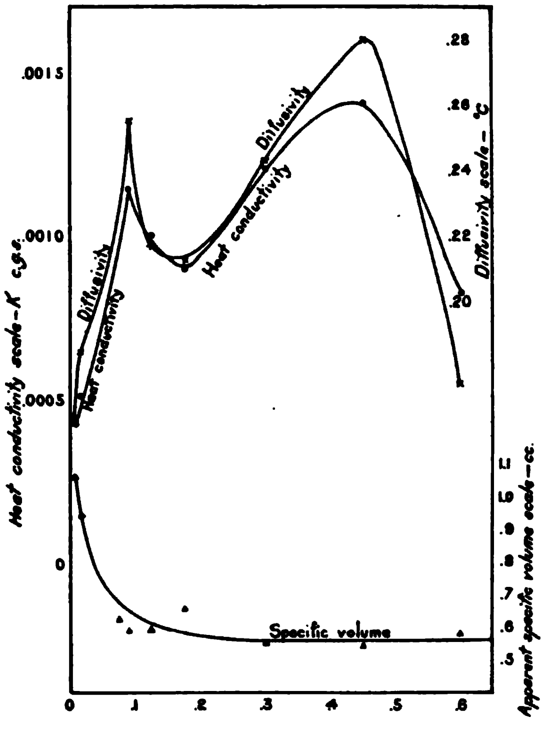

FIG. 22.—Curves showing the effect of size of grain of carborundum powder upon apparent specific volume, heat conductivity, and diffusivity.

The curve for the apparent specific volume shows a drop as the size of grain increases. The heat conductivity and diffusivity curves both show the effect of this, as they rise steeply to values about 30 per cent higher than those for the finest grade of carborundum. This influence of packing is seen, too, in the powders which lie between 0.1 and 0.2 mm. average diameter of grain. The apparent specific volume in these two cases lies higher than might be expected from the curve drawn through the first four points, and we should accordingly expect the heat conductivity and diffusivity to be lowered by the looser packing of powder thus indicated. This is exactly the case, and at the point where the powder has a grain diameter of 0.3 mm. it is seen that the heat conductivity and diffusivity have again risen, while the apparent specific volume—as it should be—is lower

TABLE XIII.—*Effect of size of grain upon heat conductivity, for air-dry carborundum powder. Summary of experimental and derived data.*

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Apparent specific volume *V*.	Moisture content on wet weight.	Moisture content on dry weight.	Effective specific heat, *C*.	Rate of rise of temperature at 5 cm. from heat source (No. 5 thermometer). $\frac{d\theta}{dt}$	Temperature at foot of No. 5 thermometer straight line rise.	Time at foot of No. 5 thermometer straight line rise.	Period required for rise of 6.3° C. at 5 cm. from heat source.	Rate of change of temperature gradient at 5 cm. from heat source for $dx=0.5$ cm. $\frac{d^2\theta}{dx^2}$	(4)×(5)=calories per gram of soil per minute.	(10)+(1)=calories per cubic centimeter per minute.	(11)+(60)=calories per cubic centimeter per second.	(12)+(9) calories per square centimeter per second per degree change in temperature gradient =K= $\frac{C}{v}\left(\frac{d\theta}{dt}\right)+\left(\frac{d^2\theta}{dx^2}\right)$	(5)+(9)=diffusivity rate of rise of temperature at 5 cm. from heat source per degree change in temperature gradient. $\left(\frac{d\theta}{dt}\right)+\left(\frac{d^2\theta}{dx^2}\right)$	Conventional name of grade.	Average diameter of grain.
cc.	*Per cent.*	*Per cent.*	*Calories.*	*° C per min.*	*° C.*	*min. sec.*	*min. sec.*	*° C. per cm.*					*° C. per min.*		*mm.*
0.584	0.0216	0.0217	0.1659	0.454	26.7	16 30	24 30	2.6	0.0753	0.1289	0.00214	0.0008231	0.1746	40	0.60
.548	.0052	.0052	.1659	.447	27.35	14 45	24 40	1.6	.0742	.1350	.00225	.001406	.2800	50	.45
.559	.0075	.0075	.1659	.389	26.6	17 40	27 55	1.6	.0646	.1153	.001923	.001202	.2431	60	.30
.659	.0076	.0076	.1659	.468	21.9	17 10	24 35	2.2	.0777	.1180	.001965	.0008932	.2127	90	.175
.601	.0039	.0039	.1659	.477	22.0	15 12	24 18	2.2	.0791	.1317	.002194	.000997	.2170	150	.125
.596	.00393	.00393	.1659	.460	19.4	18 12	26 25	1.8	.0731	.1227	.00206	.001144	.2555	180	.090
.625	.0166	.0167	.1659	.396	19.4	20 18	29 40	1.8	.0657	.1050	.00175	.000975	.2200	220	.075
.945	.086	.087	.1659	.407	21.6	20 50	29 55	2.2	.0675	.0715	.001124	.0005110	.1850	FFF	.015
1.066	.0323	.0324	.1659	.294	22.8	21 20	36 00	1.8	.0488	.0458	.000763	.000424	.1633	60′	.006

and seems to have reached its normal value. From these results it is seen that in air-dry condition No. 50 carborundum powder of average grain diameter 0.45 mm. shows the maximum heat conductivity and diffusivity and the minimum apparent specific volume. The effect of moisture films upon the carborundum surfaces is of course to increase the heat conductivity and diffusivity by securing better contact between the grains; but in this case the No. 50 carborundum powder showed about one-fourth of the moisture content given by the other coarse grade powder No. 40, and 30 per cent less than No. 60 or No. 90; consequently this maximum shown by No. 50 powder is not due to moisture.

If this maximum heat conductivity of a powder having grains 0.45 mm. in diameter be applied in the case of an air-dry soil, one may expect to find the best conduction in the case of a medium sand whose grains are officially classified as ranging between 0.5 and 0.25 mm. in diameter.

For assistance in making experimental observations and calculations, acknowledgments are due to Mr. J. M. Jester.

GENERAL DISCUSSION OF RESULTS.

The transfer of heat from one soil particle to another is influenced by the fluid filling the space between them, and of course this transfer is more easily effected when the fluid is a good conductor of heat. In addition to the heat conductivity of the fluid, another factor has to be considered; that is, the resistance to the heat transfer which is found at the boundary between the substances in contact. This "transfer resistance," or its reciprocal, "transfer conductivity," is of sufficient magnitude to enter into thermal calculations.

If the fluid be in motion, there will be developed a resistance to the transfer of heat which has been shown to vary approximately with the square root of the velocity of the fluid. The transfer conductivity for the fluids air and water may be roughly compared as follows:

When heat passes from metal to air, the transfer conductivity is given by the equation,

$$K = 0.000,028(2 + \sqrt{v}),$$

where v is the velocity with which the air passes the surface of the metal.

For the passage of heat from water to metal, this transfer resistance is much less, as shown by the greater transfer conductivity,

$$K = 0.000,028(300 + 180\sqrt{v}).$$

Assuming $v = 1$ cm. per second in each case, K for air to metal is 0.000,084; while for water to metal K is 0.01344; that is, the heat passes from water to metal about sixteen hundred times more readily than from air to metal, at this unit velocity of 1 cm. per second.

For a soil: Assume (1) that the velocity of soil atmosphere in a dry soil is very nearly zero; and (2) that the velocity of soil water in a wet soil be nearly zero; and (3) that the transfer conductivity of soil material to gas and to water has the same ratio as that which holds for the transfer conductivity of a metal to gas and to water.[a]

Then the above equations indicate that heat will pass from a soil grain to soil water one hundred and fifty times easier than from a soil grain to soil atmosphere. This comparison seems to point out one reason why an air-dry soil shows such a low heat conductivity. The rapid circulation of soil atmosphere as eddy currents within the minute spaces between the soil grains would, however, decrease very greatly the transfer resistance. Such eddy currents are inevitably set up as the hot-soil atmosphere on one side of a soil cavity expands and moves up and is replaced by the colder gases.

Consider the air-dry soils: It is seen in Table XIV that where the apparent specific volume (the packing) is about the same the heat conductivities are very nearly the same. Fine quartz flour shows about one-half the conductivity of the other air-dry soils, but this is due in part to its high apparent specific volume. Comparing the moisture film expressed as grams water per square centimeter of soil grain area, it is seen that the coarse quartz has a film of water some nine times heavier than that on the grains of the fine quartz flour, and from this one would expect better contact between the grains of coarse quartz and better heat transfer, as is the case. This good contact between soil grains may also be secured by the smaller sizes of grains wedging into the spaces between the larger sizes. Thus, Leonardtown silt loam shows a higher heat conductivity than Podunk fine sandy loam, although the moisture film per square centimeter on the Podunk soil grains is heavier than that on the Leonardtown soil grains. The Leonardtown soil contains more clay and silt, and these assist in securing the transfer of heat through the soil.

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[a] See Preston, "Theory of Heat."

TABLE XIV.—*Data showing the relation between area, moisture film, and heat conductivity and diffusivity of air-dry soils.*

Name of soil.	Moisture content.	Apparent specific volume.	Area per gram.	Weight of water per sq. cm. of soil surface.	Heat conductivity *K*.	Diffusivity, rise per minute, 1 degree gradient.
	Per cent (on wet weight).	*cc.*	*sq. cm.*	*Grams.*	*C. g. s. units.*	*°C.*
Coarse quartz	0.095	0.601	97	0.000,009,8	0.000917	0.173
Fine quartz	.083	1.130	740	.000,001,12	.000407	.144
Hudson River sand	.256	.738	345	.000,007,1	.000654	.1613
Podunk fine sandy loam	.267	.698	415	.000,006,43	.000792	.179
Leonardtown silt loam	.80	.828	1,892	.000,004,2	.000882	.185
Muck soil	3.78	.895	(?)6,000	.000,006,3	.000349	.0999
No. 4 sand	.018	.648	137	.000,001,3	.00075	.159
Hagerstown loam	1.11	.949	2,270	.000,004,4	.000699	.199
Galveston clay	1.39	.949	3,290	.000,004,24	.000577	.149
Norfolk sand	.1	.750	300	(?).000,003,3	(?).006	(?)1.5

These values for the area of each soil per gram as shown in Table XIV are, of course, very rough. They were calculated from the mechanical analyses given above for each soil, assuming the soil grains to be spheres. Still these rough values, when used with the moisture contents, serve to give a picture of the probable dimensions of the film of water surrounding the soil grains and making contact between them, and thus afford a better idea of the relation of soil moisture to heat conductivity.

For the muck soil no mechanical analysis was made, since it would be meaningless. The area per gram was taken as a very rough approximation by comparing the heat given out on wetting this soil with the heat evolved by other soils, whose mechanical analysis is available, as shown in Table IV. It is interesting to note that using this extremely crude method of comparison the moisture film upon the muck soil appears to be of the same order of magnitude as the films on the other soils.

The heat conductivity of water as given by Lees[a] is 0.00149 (metric) for *K*. Consequently the heat conductivity of soil and water mixtures eventually must approach this value as the percentage of soil in the water decreases. The increase in heat conductivity of a soil produced by wetting it is then entirely due to the better contact between the soil grains thus produced, since the soil material has in continuous massive condition a much higher heat conductivity than water.

When the heat conductivity of soil increases (on wetting) as a nearly linear function of the moisture present, it means that the good contact secured between the soil grains by the soil moisture has an effect enough greater than linear to make up the decrease in heat conductivity which is produced by the addition of water—a substance whose heat conductivity is approximately one-seventh [a] that of the soil material when compacted into rock. Thus, coarse quartz powder when saturated with water (20 per cent on the wet weight) shows a lower heat conductivity than finer-grained soils at the same moisture content, since a larger fraction of the water is held by the coarse quartz in larger intergrain cavities where the heat conductivity of water is a greater factor in the heat transfer than the function of the water in securing contact between the quartz grains.

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[a] Phil. Mag. (5), **49**, 289 (1900).

The diffusivity curve for coarse quartz goes through a maximum at 5.5 per cent of moisture, whereas the maximum apparent specific volume of coarse quartz comes at a lower moisture content—about 3 per cent—as shown in figure 13. This same lack of agreement between optimum water content and maximum diffusivity is seen in figure 14 for the fine quartz flour, which has a maximum apparent specific volume at about 11 per cent of moisture and a maximum diffusivity at 16 per cent of moisture (calculated on the wet weight). Inspection of figures 15, 16, 17, and 18 shows that this is a general characteristic of widely differing soil types; i. e., the optimum water content of each soil studied lies below the percentage of water which gives to the soil its highest diffusivity.

The reason for this is that at the optimum water content we have the soil grains formed into larger aggregates and the spaces between these aggregates act as an air insulation against the passage of heat. As more water is added some of these soil grain aggregates break up and their constitutent grains now serve to fill in the spaces between the larger aggregates, and the added water gives still better contact between the soil crumbs and the small grains. Thus the total effect is a better conduction of heat and a faster rise of temperature. But when water is added to the soil over a certain percentage (which is different for each soil) the temperature of the soil will rise more slowly, although heat is being conducted by the soil better than at a lower moisture content. This effect is produced by the high heat capacity of water, which is almost five times that of a dry soil.

For purposes of comparison and for convenient reference the heat conductivities of water, ice, rocks, and soils, together with the sources of the data and names of the experimenters, are given in Table XV.[b] The conductivities headed "Eng. K" are the values of K to be used in the formula $q=\frac{K\,a\,t}{x}$, where q is the heat, in British thermal units, which will pass between the bases of a right prism

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[a] For sandstone, $K=0.01066$, according to Forbes in Tait on Heat.

[b] This set of conductivities was kindly furnished us by Mr. S. H. Woodard, resident engineer of the East River Division, Pennsylvania Tunnel and Terminal Railroad Company.

"*a*" square feet in area, *x* feet apart and at a difference of *t* degrees Fahrenheit in *one hour*. The conductivities headed "Metric *K*" are the values to be used for "*K*" in the same formula when all factors are in the C. G. S. units, and *q* then represents calories in *one second;* *a*, area in square centimeters; *t* the temperature difference in degrees centigrade; and *x* the distance, between the bases of the prism of reference, in centimeters.

TABLE XV.—*Heat conductivities.*

Material.	Eng. *K*.	Metric *K*.	Reference.	Experimenter.
Water	0.33867	0.00140	Philos. Mag., vol. 49	Chas. H. Lees.
Do	.36044	.00149	do	Do.
Do	.35803	.00148	do	Do.
Do	.32899	.00136	Royal Soc. London, vol. 191	Do.
Do	.32899	.00136	Barker's Physics	Weber.
Do	.48381	.0020	Glazebrook's Heat	Forbes.
Ice	1.3789	.0057	Barker's Physics	Neumann.
Do	.53945	.00223	Science Lectures at So. Kensington, vol. II, p. 25.	Forbes.
Do	.55638	.0023	do	Lucien de la Rive.
Sand	.17901	.000740	Royal Soc. London, V. 65, p. 285	Lamb and Wilson.
Do	.62895	.0026	Glazebrook's Heat	Forbes.
Do	.63379	.00262	Science Lect. at So. Kensington	Do.
Do	.63137	.00261	Carpenter's Heating and Ventilation	
Sandy soil	[a].660	.00271	Tait on Heat	
Sandy loam	3.28992	.0136	Am. Acad. Arts and Sci., vol. 38, No. 23, May, 1903.	Neumann.
Greenwich Park gravel (damp).	3.02382	.0125	do	Everett.
Sandstone	2.58355	.01068	Sci. Lect. So. Kensington	Forbes.
Do	[a]2.58	.01066	Tait on Heat	Do.
Sandstone and hard dry grit.	1.33048	.0055	Am. Acad. Arts and Sci. vol. 38, No. 23.	Herschel, Lebour, and Dunn.[b]
Craigleith Quarry sandstone (damp).	2.58839	.0107	do	Kelvin.
Limestone:				
Fine-grained	1.2228	.005055	Reck	Peclet.
Coarse-grained	.87352	.003611	do	Do.
Porphyritic trachyte.	1.4246	.00589	Carpenter's Heating and Ventilation	Do.
Trap	1.0039	.00415	Sci. Lect. So. Kensington	Forbes.
Do	1.00802	.004167	Carpenter's Heating and Ventilation	
Trap:				
Density=2.90	.74991	.0031	Amer. Acad., vol. 38, No. 23, May, 1903.	B. O. Pierce.
Density=2.82	.87086	.0036	do	Do.
Whinstone trap rock.	.67733 to 1.16115	.0028 to .0048	do	H. L. and D.[b]
Calton Hill trap (damp).	1.01600	.0042	do	Kelvin.
Amygdaloid:				
Density=2.67	.84667	.0035	do	B. O. Pierce.
Density=2.71	.82248	.0034	do	Do.
Conglomerate:				
Density=2.55	1.13695	.0047	do	Do.
Density=2.64	1.25791	.0052	do	Do.
Tough dry clay	.53219	.0022	do	H. L. and D.[b]
Devonshire clay slate.	.65315	.0027	do	Do.
Serpentine	1.42724	.0059	do	Neumann.
Cornish red serpentine.	1.06438	.0044	do	H. L. and D.[b]
Caen stone	1.04019	.0043	Am. Acad., vol. 38, No. 23, May, 1903	Do.
Chalk	.48381 to .79828	.0020 to .0033	do	Do.
Marble	1.71753	.00710	Philos. Mag., vol. 49	Chas. H. Lees.
Marble, fine grained, gray.	2.3385	.009667	Reck	Peclet.
Marble, coarse grained, white.	1.86751	.00772	do	Do.
Marble	1.52401	.0063	Wiedemann's Annalen, bd. 14, 1881, p. 23.	C. Christiansen.
Marble, fine grained	1.69334	[c].007	Amer. Acad	Peirce and Willson.
Marble, coarse grained	1.33048	.0055	do	Do.
Carrara white marble.	1.23372	.0051	Vol. 38, No. 23	Do.

[a] Given. [b] For British Association. [c] Average of fifteen experiments.

TABLE XV.—*Heat conductivities*—Continued.

Material.	Eng. *K*.	Metric *K*.	Reference.	Experimenter.
American and Italian colored marbles.	1.49982 to 1.83848	0.0062 to .0076	Vol. 38, No. 23	Peirce and Willson.
Sugar-white marble	1.86267	.0077	do.	Despretz.
Marble, fine grained, gray.	2.34648	.0097	do.	Do.
English marbles and limestones.	1.1370 to 1.35467	.0047 to .0056	do.	H. L. and D.[a]
Granite	1.28210	.0053	Amer. Acad., vol. 38, No. 23	Do.
Glass	.67008	.00277	Am. Acad. Arts and Sci	Peirce and Willson.
Do	.55101	.002278	Carpenter's Heating and Ventilation	Peclet.
Do	.50389	.002082	Reck	Do.
Do	.120953	.0005	Glazebrook's Heat	Forbes.
Do	.59267	.00245	Royal Soc., London	Chas. H. Lees.
Glass, English plate	.55638	.0023	Am. Acad., vol. 38, No. 23	H. L. and D.[a]
Glass, American plate	.62895 to .67733	.0026 to .0028	do.	Peirce and Willson.

[a] For British Association.

Likewise the results of Hutton and Beard[a] are given in Table XVI, the heat conductivities being calculated in the metric system, and thus corresponding to the values given in Table XV under the heading "Metric *K*."

Table XVII contains a similar set of data taken from J. W. Richards' Metallurgical Calculations.[b] Here, too, the conductivities are given in the metric units.

TABLE XVI.—*Heat conductivities.*

[Results of Hutton and Beard.]

Material.	Metric *K*.	Material.	Metric *K*.
Sand, white Calais	0.00060	Lime	0.00029
Carborundum, fine	.00050	Magnesia, fused	.00047
coarse	.00051	"Mabor" brick	.00050
Quarts, "enamel"	.00036	calcined Greek	.00045
fused	.00039	calcined "Veitsch"	.00034
Fire brick	.00028	Pattinson's light calcined	.00016
Retort graphite	.00040	Kieselguhr (infusorial earth)	.00013

[a] Electrochem. and Met. Ind., 3, 201 (1905).

[b] Electrochem. and Met. Ind., 4, 102 (1906).

TABLE XVII.—*Heat conductivities.*

[From J. W. Richards' Metallurgical Calculations.]

Material.	Metric *K*.
Ice (datum useful in refrigerating plants, where pipes become coated with ice, as in Gayley's method of drying blast)	0.00500
Snow	.00050
Glass (10°-15°)	.00150
Water	.00120
Quartz sand (18°-98°)	.00060
Carborundum sand (18°-98°)	.00050
Silicate enamel (20°-98°). (Explains the small conductance of enameled iron ware)	.00040
Fire-brick dust (20°-98°)	.00028
Retort graphite dust (20°-100°). (Datum useful where articles are packed in this poorly conducting material)	.00040
Lime (20°-98°). (Datum would be highly useful for oxyhydrogen platinum furnaces, if it were only known at high temperatures)	.00029
Magnesia brick, dust (20°-100°)	.00050
Magnesia calcined, Grecian, granular (20°-100°)	.00045
Magnesia calcined, Styrian, granular (20°-100°)	.00034
Magnesia calcined, light, porous (20°-100°)	.00016
Infusorial earth (Kieselguhr (17°-98°)	.00013
Infusorial earth (0°-650°)	0.00038
Clinker, in small grains (0°-700°)	.00110
Coarse ordinary brick dust (0°-100°)	.00039
Chalk (0°-100°)	.00028
Wood ashes (0°-100°)	.00017
Powdered charcoal (0°-100°)	.00022
Powdered coke (0°-100°)	.00044
Gas retort carbon, solid (0°-100°)	.01477
Cement (0°-700°)	.00017
Alumina bricks (0°-700°)	.00204
Magnesia bricks (0°-1,300°)	.00620
Fire bricks (0°-1,300°)	.00310
Fire bricks (0°-500°)	.00140
Marble, white (0°)	.0017
Pumice	.0006
Plaster of Paris	.0013
Felt	.000087
Paper	.00040
Cotton	.000040
Wool	.000035
Slate	.00081
Lava	.00008
Pumice	.00060
Cork	.00072
Pine wood	.00047
Oak wood	.00060
Rubber	.00047

Issued September 29, 1909.

U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF SOILS—BULLETIN NO. 60.

MILTON WHITNEY, Chief.

A PRELIMINARY REPORT ON THE VOLUSIA SOILS, THEIR PROBLEMS AND MANAGEMENT.

BY

M. EARL CARR.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1909.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., May 19, 1909.

Sir: I have the honor to transmit a manuscript entitled "A Preliminary Report on the Volusia Soils, their Problems and Management," by M. Earl Carr, of this Bureau. This report is based upon the information gained in soil surveys situated in different parts of the wide region occupied by the important Volusia series of soils, augmented by special study of the soil conditions in parts of the region where soil surveys have not yet been undertaken. The Volusia series of soils occupies a belt of country in southern New York, northern Pennsylvania, and northeastern Ohio, covering an area of over 10,000,000 acres. For twenty-five years the general tendency in prices of farms in this region has been downward and in some localities actual agricultural abandonment of the land has resulted. The soil conditions affecting this economic problem are discussed in this report and the facts set forth therein should result in the removal of the impression that these soils are "worn out" or inherently incapable of profitable crop production. The report should lead to a restoration of confidence concerning the capabilities of these soils, and if an increase in agricultural value of $1 an acre can thus be brought about the sum of over $10,000,000 will be involved. The report discusses fully the characteristics of these soils and their capabilities, treating briefly the general soil problems encountered and their bearing upon the economic problems of the region.

I recommend the publication of this report as Bulletin No. 60 of the Bureau of Soils.

Very respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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A PRELIMINARY REPORT ON THE VOLUSIA SOILS, THEIR PROBLEMS AND MANAGEMENT.

INTRODUCTION.

The Volusia[a] series of soils occurs in a more or less extended belt, covering the glaciated portion of the Allegheny Plateau in northeastern Ohio, northwestern and northeastern Pennsylvania, and southern and south-central New York. These soils cover an approximate area of from 15,000 to 20,000 square miles, or something over 10,000,000 acres. They are the hill soils of the region, always being

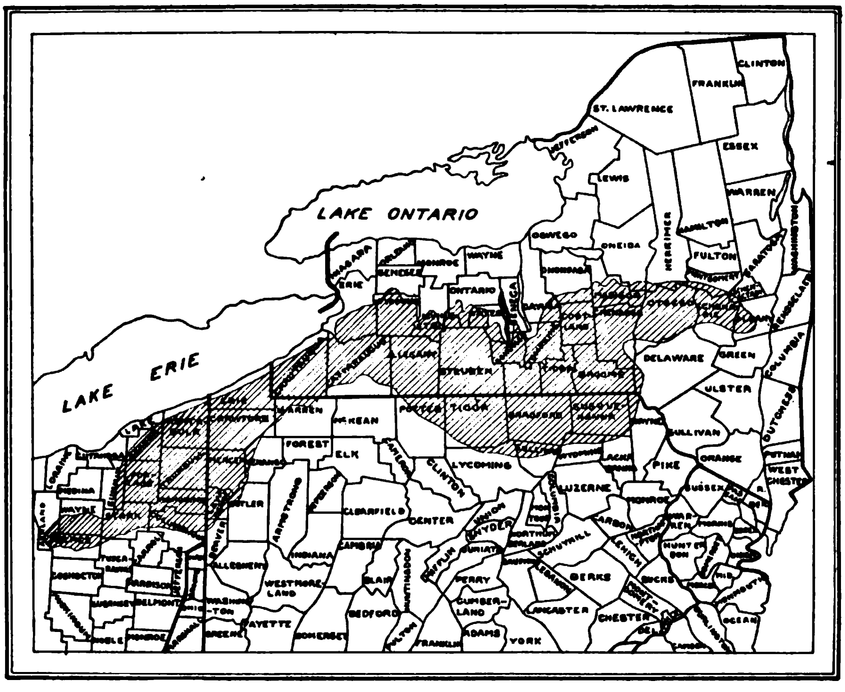

FIG. 1.—Sketch map showing the region occupied by Volusia soils in Ohio, Pennsylvania, and New York.

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[a] The soil series name "Volusia," adopted to identify this group of soils, is that of a small village in Chautauqua County, N. Y., where they were first encountered and mapped in 1901.

found at relatively high altitudes, while the narrow valleys occurring within the same general region are occupied by other soils and soil series, differing in origin, method of formation, structure, coloration, and other properties.

The acreage of each type of soil in the Volusia series mapped to January 1, 1909, in New York, Pennsylvania, and Ohio, and the total area for all three States are as follows:

Area of Volusia soils mapped to January 1, 1909.

State and kind of survey.	Type of soil.	Area of individual type.	Total area.
		Acres.	*Acres.*
Pennsylvania, reconnoissance survey, all types			1,840,000
Ohio, detailed surveys	Loam	173,440	251,904
	Silt loam	78,464	
New York, detailed surveys	Stony loam	12,352	862,050
	Gravelly loam	13,760	
	Loam	329,954	
	Silt loam	500,032	
	Clay loam	5,952	
Total, detailed surveys			1,113,954
Total, all surveys			2,953,954

The area mapped comprises 4,615½ square miles, or about 25 per cent of the estimated area of the series.

DESCRIPTION OF SOILS.

The Volusia soils are derived through feeble glaciation from shales and sandstones of Devonian and Upper Carboniferous ages. While the soil-forming material is primarily made up of material from these country rocks moved only a comparatively short distance, there is usually a small percentage of glacial material foreign to the immediate locality. In many places residual decay of the underlying rock has added largely to the material forming these soils, particularly in the case of the silt loam type. The underlying shales and sandstones are almost always comparatively near the surface. In fact, the glacial material is often so shallow that the bed rock is found within a 3-foot section, and it outcrops in not a few instances. While these Volusia soils are generally shallow, the soils occurring in the valleys are much deeper, the underlying rock often being several hundred feet beneath the surface.

The soils of the Volusia series are light colored—grays, light yellows, and light browns predominating. Where the soil is in poor condition the lighter colors are very much in evidence, there is a lack of drainage, a deficiency of organic matter, poor herbage, and a generally inert, lifeless appearance. Where the better soil conditions obtain the colors are darker and warmer, a larger content of organic matter is present, the drainage conditions are better, better herbage prevails, and the soil is marked by a more healthy, lively appearance, all of which are reflected in larger and better crop yields. In contrast with the soils of the Volusia series the valley soils are characterized by darker colors—browns and dark grays to black being much more frequent. Natural drainage conditions are better, the organic matter content higher, and a far better quality and quantity of herbage is supported. The influences of all these differences in favor of the valley soils are shown by differences in the soil problems, by a wider range in adaptation to crops, by different types of farm industry, by better crop producing power, and finally, by a higher market value of the valley lands.

The Volusia silt loam is the most extensive type of the series so far encountered, making up about 50 per cent of the area covered by detailed surveys. The surface soil of this type consists of a gray, light-brown, or pale-yellow silt loam with a depth of some 8 or 9 inches. The subsoil is a gray or yellowish compact silt loam. Both soil and subsoil contain a varying but usually high percentage of flat shale and sandstone fragments. The physiographic features of this type of soil are characteristic. It always occurs on the hills and at comparatively high altitudes. Preglacial erosion has developed a varied topography and favored the development of an excellent system of surface drainage. On account of the hilly topography there is a considerable percentage of waste land.

The Volusia loam is the most important agricultural soil of the Volusia series. It consists of a surface loam 8 to 10 inches in depth, having a dark-gray to light-brown color and a subsoil of gray to mottled compact loam, composed of glacial till. Both soil and subsoil of this type are more or less filled with stone fragments, the sandstone and foreign rock material being somewhat greater than in the silt loam type.

This type like the silt loam has a hilly topography, though lying usually at slightly lower altitudes, and the natural surface drainage is the same. It, however, has generally a somewhat less broken topography, and waste land on this account forms a smaller proportion of its area.

The Volusia gravelly loam has a more limited area than the soils just described, but is the lightest, warmest, and earliest soil of the series. It is a gravelly loam extending usually to depths greater than 3 feet, the surface soil being as a rule light-brown in color, and the gravel content for the most part rounded and waterworn. The topography is often quite broken and rough, owing in part to the processes by which it was formed and in part to erosion subsequent to its deposition.

The Volusia stony loam is of small extent, so far having been mapped only in one area, Tompkins County, N. Y. The soil consists of a heavy dark-brown loam containing a large quantity of flat shale and also a considerable proportion of rounded stones and cobbles. The subsoil to a depth of 3 feet is a light loam, sometimes containing large quantities of stone and gravel. This soil type as so far encountered has a rolling topography particularly favorable for agricultural occupation, with a minimum percentage of waste hilly land.

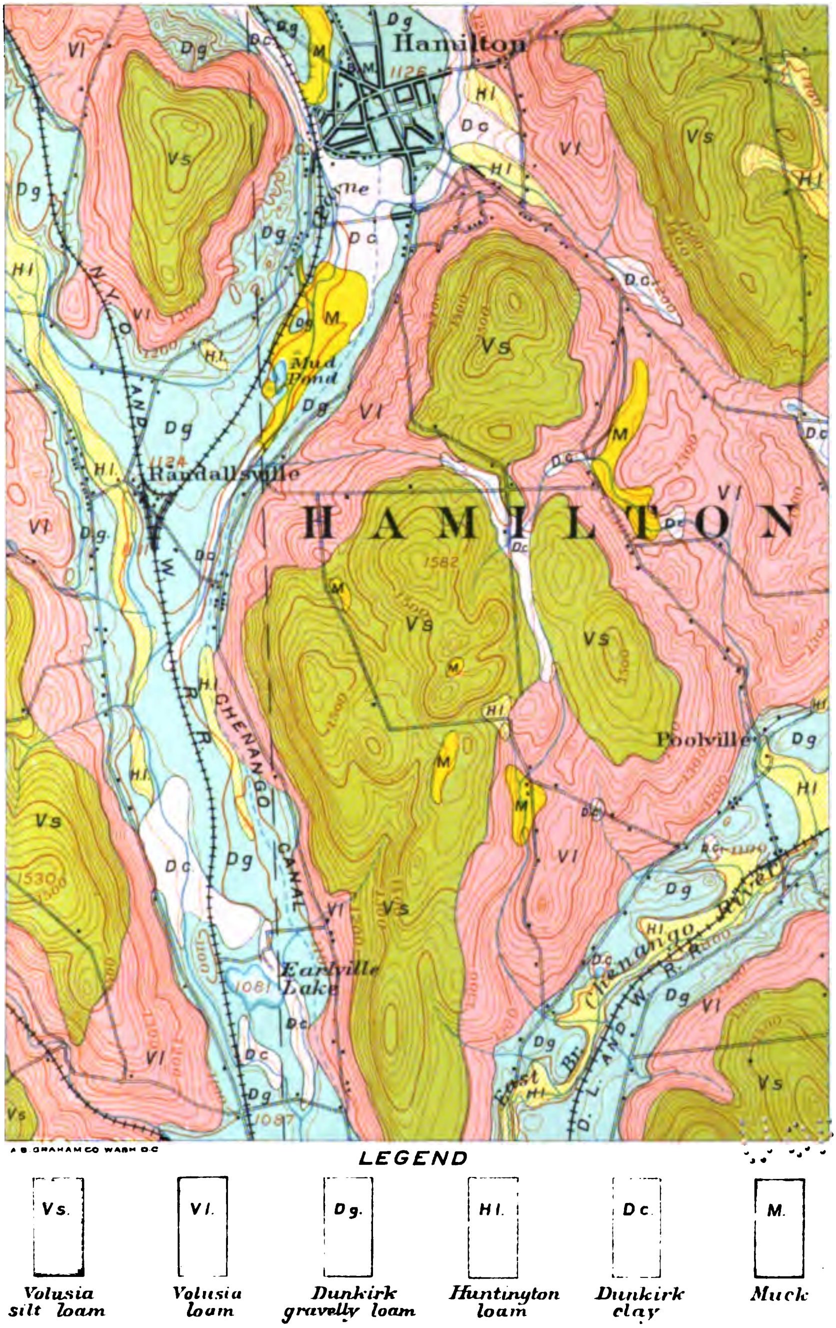
The Volusia clay loam is also of very limited extent, not having been encountered outside of Tompkins County, N. Y. It has a surface soil 6 to 8 inches in depth, of dark-yellow to brown heavy loam or clay loam, underlain by a subsoil of pale-yellow or drab clay loam. This type is rolling rather than hilly and the surface conditions are quite favorable for agriculture.

AGRICULTURAL CONDITIONS.

The agricultural conditions prevailing over areas of the Volusia soils are not at the present time all that can be desired and certainly not all that is warranted by the inherent capabilities of the soil. This is particularly true of the silt loam and to a less degree of the loam and the other types of the series. There are soil conditions and soil problems which make the agriculture of some sections extremely poor. That these same soil conditions and problems do not obtain on the valley soils of the region or on the soils located in the lower lying region to the north of the country occupied by the Volusia soils is proved by the prevalence of much better agricultural conditions, more intensive systems of farming, the larger crop yields, and the higher prices at which these other soils are held.

When the region in which the Volusia soils occur was first cleared of its forests of chestnut, oak, white pine, sugar maple, beech, and hemlock large yields of the staple crops, wheat, corn, oats, and hay, were secured. No difficulty was experienced in the growing of red clover or other crops. The region was fairly well populated, the families large, and the farmers prosperous. However, there has developed a condition of the soil, especially in the silt loam areas, which is inimical to some forms of plant life. That this condition is a soil and not a plant problem is evident both from field observation and experimental work.

Many farms and fields can now be found where red clover and other crops still grow well, and in the same region, perhaps on an adjoining farm or field, they give indifferent results, or refuse to grow at all. The soil of newly cleared fields seldom fails to produce crops and give good yields, while adjoining or near-by fields which have been cleared and cropped for a good many years produce poor crops, or crops of no commercial value, though when first cleared and



A. B. GRAHAM CO. WASH. D.C.

PART OF MADISON COUNTY, N.Y., SOIL MAP, SHOWING THE TOPOGRAPHY AND RELATION OF THE VOLUSIA (HILL) SOILS TO THE VALLEY SOILS

cropped they were as productive as the fields now being brought under cultivation.

A recent bulletin[a] of the New York State College of Agriculture, based upon experimental work on these soils and dealing with the failure of red clover on them, states that this failure of the clover is not due to any fungous disease of the clover plant, that it is not due to the lack of the proper kind of bacteria in the soil, or to other influences of such a character. In fact every plant problem is eliminated from the question, and the conclusion is that the soil and soil condition alone are responsible for the "clover sickness" of the Volusia soils.

Moreover, on many fields which either refuse to grow the red varieties of clover or produce poor stands alsike clover does well, and, further, a chemical analysis of the soil by standard methods shows a sufficient amount of the common plant-food elements for successful crop growth.

In recent years extreme difficulty has been experienced in seeding clover, amounting in many cases to complete failure. Corn seldom gives any yield of mature grain; wheat yields have become so low that attempts to grow this crop have been abandoned; families are small, in some school districts the population being so sparse that the schoolhouses are closed and going to ruin. In the region occupied by the silt loam many farm homes are abandoned; the farm buildings are fast going to ruin; once productive fields are abandoned so far as profitable agriculture is concerned. These fields are growing up to weeds and in a few cases to a second growth of timber, worthless except for firewood. Many of these fields are not even being utilized for pasturage, and the present tenantry make only a poor living. As a single specific example of these two conditions the following statements are given concerning an 80-acre farm of Volusia silt loam:

In 1883 this farm produced clover hay at the rate of 2½ tons per acre for the first cutting, and clover seed from the second growth at the rate of 4 bushels per acre; nearly $700 worth of grain was produced and sold, and 3 cows, 20 sheep, and a team were kept. The total yield of all crops for each of the past five seasons grown on this farm would not support more than the 20 sheep and nothing was sold. No clover is grown, and it can not be grown by the methods now in practice. On a neighboring farm property of over 100 acres the total product for the season of 1907 was two small stacks of very poor quality hay, not over 6 to 8 tons.

The first of these farms sold in 1883 for $37.50 an acre, while in 1909 the second farm, which is neither better nor worse, was sold for about $5 an acre. A number of farms have recently been sold in this same region for taxes and brought only a few dollars an acre.

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[a] Bul. No. 264 Cornell Univ. Agr. Expt. Sta., by J. H. Squires.

These figures are a fair sample of the worst conditions both as to decline in crop yields and depreciation of farm-land values in the region occupied by the Volusia soils.

The decrease in rural population referred to above, amounting to 1,015 for the past forty years and 923 for the past twenty-five years, or about 15 per square mile, is vividly shown by the following census figures for the township in which the two farms mentioned are located:

Decrease in population of a township occupied largely by Volusia soil.

Year.	Census.	Population.
1865	State	2,700
1875	do	2,524
1880	Federal	2,608
1890	do	2,215
1892	State	2,195
1900	Federal	1,902
1905	State	1,685
Decrease in forty years		1,015
Per cent decrease in forty years		37.6

These figures, while representing extreme conditions, clearly indicate the trend in some parts of the region occupied by the Volusia soils.

That these unfavorable circumstances are unnecessary is evidenced by the existence of conditions which are the exact reverse of those cited. In the same region, on a soil identically the same and in the same poor condition, producing no clover, and yielding one-half ton of hay per acre in 1907, 1 acre produced 250 bushels of potatoes without fertilization of any kind in 1908. In other sections covered by soils of the Volusia series, clover gives good yields and the yields of other crops adapted to the soils are excellent. On individual farms the farmers are prosperous and land values are not depressed and the rural population is not decreasing, but is either stationary or slightly increasing. These favorable conditions are all encountered in regions where the adaptation of the Volusia soils to the production of Irish potatoes has been recognized and put into practice, and on farms where a goodly number of live stock are kept and fed, and where drainage conditions are better. The first point is vividly shown in Steuben County, N. Y., where these Volusia soils have made the county the third potato producing county in the country. This county is also the only strictly rural county in New York which showed an increase in farm value for the two decades, 1880 to 1890 and 1890 to 1900.

The important soil problems presented by the Volusia soils can be considered under five heads—physical condition, drainage, organic matter constituents, acidity, and so-called "clover sickness."

PHYSICAL CONDITION.

When these soils were first cleared and in their virgin state, the physical condition was favorable for the successful growth of many different crops, but with the continuous cropping to which they have been subjected, the methods of farming followed, and the systems of soil management practiced, the physical condition has changed and is now to a large extent unfavorable for the production of the same crops.

The texture of the loam and silt loam types is not particularly favorable for many crops. The average for 10 samples of the silt loam shows about 80 per cent of silt and clay and about 20 per cent of coarser material, about half of which is very fine sand, only one degree removed from the silt in fineness. Considering the textural feature apart from all other factors, it is favorable to puddling and baking, and as a matter of fact this tendency is decidedly pronounced wherever the influence of some other factor or set of factors is not present to have a counteracting effect.

The structure of both of these soil types, especially in areas which are in the poorer condition, is not as favorable for crop growth as when they were first cleared or as it is in many soils of similar and even heavier texture but of different origin, coloration, and other physical characteristics. Flocculation of the soil grains seems to be entirely lacking, and consequently the puddling and baking of the surface take place easily. A granular structure and its attending effects would facilitate desirable and beneficial moisture movements, aeration, and oxidation, all of which are necessary for the production of even ordinary yields of our farm crops. Such structure should be attained by proper drainage, liming, and the incorporation of organic matter. Another feature in connection with the structure of these soils is the occurrence of a " hardpan " in the subsoil. This hardpan is often quite near the surface and limits the depth of the surface soil and seed bed and consequently the root development of all crops, except those which are very shallow rooted, like alsike clover. It often occurs at 12 to 24 inches beneath the surface, and while its occurrence at this depth does not affect the depth and preparation of the seed bed it does have a decided effect on the root development, similar to that where it occurs nearer the surface, through its influence on soil moisture conditions.

This hardpan of the Volusia soils is not unlike the remainder of the section in texture, but consists of a compacted stratum having a dense, close structure. In not a few cases its development has at least been aided by continuous plowing at the same depth year after year. It is also brought about by plowing the soil when the subsoil is too wet, even though the surface soil may have become sufficiently dry for tillage. By these practices the plow sole has pressed the soil grains together each time it has passed along, until finally a dense, impervious structure has been formed just beneath the surface soil, resulting in the compacted stratum called "hardpan." This layer holds the water above it in wet weather and prevents its rise from below in times of drought.

DRAINAGE.

Although the natural surface drainage of the Volusia soils is well developed, as previously stated, the internal drainage is often poor and inefficient. Both the texture and structure of the soil are unfavorable to the free movement of soil moisture. The puddling, previously discussed, either prevents the passage of drainage water and capillary soil moisture or confines their movements to a very limited space. The hardpan also restricts greatly the vertical moisture movements. The influence of all three of these factors combined is such that only a little excess of meteoric waters is necessary to waterlog completely the section overlying the hardpan subsoil and to bring about a condition extremely unfavorable for domesticated plants.

It is likewise true that the same factors prevent the absorption and retention of a sufficient amount of moisture to tide the crops over periods of drought, and consequently only a slight deficiency of rainfall is necessary to bring about conditions as unfavorable to crop growth as the other extreme of saturation. Furthermore, there is a very poor development of natural drainage channels within the soil itself.

All these characteristics combined make the drainage conditions of the Volusia soils poor and consequently the heavier soils of the series are much in need of artificial drainage.

ORGANIC MATTER.

Another soil problem in connection with the Volusia soils is that of organic matter, which is of great importance in crop production. That this is a soil and not a plant problem is shown by the different forms organic matter assumes in decaying in different soils, by the different rates of decomposition in different soils, and finally by the varied effects it has upon further plant growth in different soils.

It has been observed that the decay or partial decay of organic matter in many soils results in dark and warm colors and that its favorable effects persist for long periods of time, but that when this decay of organic matter takes place in the Volusia soils the resulting colors are not so dark and the resultant favorable effects are not of so long duration. It may be that the decomposition of organic matter in some soils results to a considerable extent in solid carbonaceous products with a minimum of gaseous matter, while the decomposition in other soils, like the soils in question, results largely in gaseous products with a minimum of the carbonaceous forms.

ACIDITY.

In regard to the chemical condition of these soils it is evident that there has been developed an acid condition, which makes the production of certain crops most difficult and which has led in many instances to the abandonment of attempts to grow them.

The accumulated effects of all of these unfavorable soil conditions have been, it is believed, the chief cause of the decline of productiveness of considerable areas of these soils, leading to the abandonment of fields, the desertion of farm homes, and the consequent decrease in population and diminution in farm land values.

"CLOVER SICKNESS."

In connection with the problems discussed there is another soil problem, the cause of so-called "clover sickness" and its remedy. While the bacterium necessary to the thrifty growth of clover is present in the soils, the poor physical condition and attending poor internal drainage conditions, together with the low organic matter content and soil acidity, result in conditions inhibitive of its development and activity. In the Volusia soils the drainage features, character of organic content, and degree of acidity are all particularly inimical to the beneficial forms of bacteria. Coincident with these conditions is the "clover sickness" of the soil. There are large areas within these soils where red clovers fail to grow, though they once were produced abundantly without difficulty, both for hay and seed. As a matter of fact the red varieties of clover will not grow naturally, and can not be made to grow where all the conditions mentioned obtain and rarely where they exist singly.

In some sections of the country "clover sickness" is purely a plant problem, but in the case of the Volusia soils it is purely a soil problem. Fungous diseases, the root borer, the absence of bacteria, in fact, all plant problems connected with its failure, have been eliminated, and the whole question hinges directly upon the physical, mechanical, and chemical condition of the soil. When these unfavorable soil conditions are overcome clover will grow, and it will not grow successfully until they are overcome.

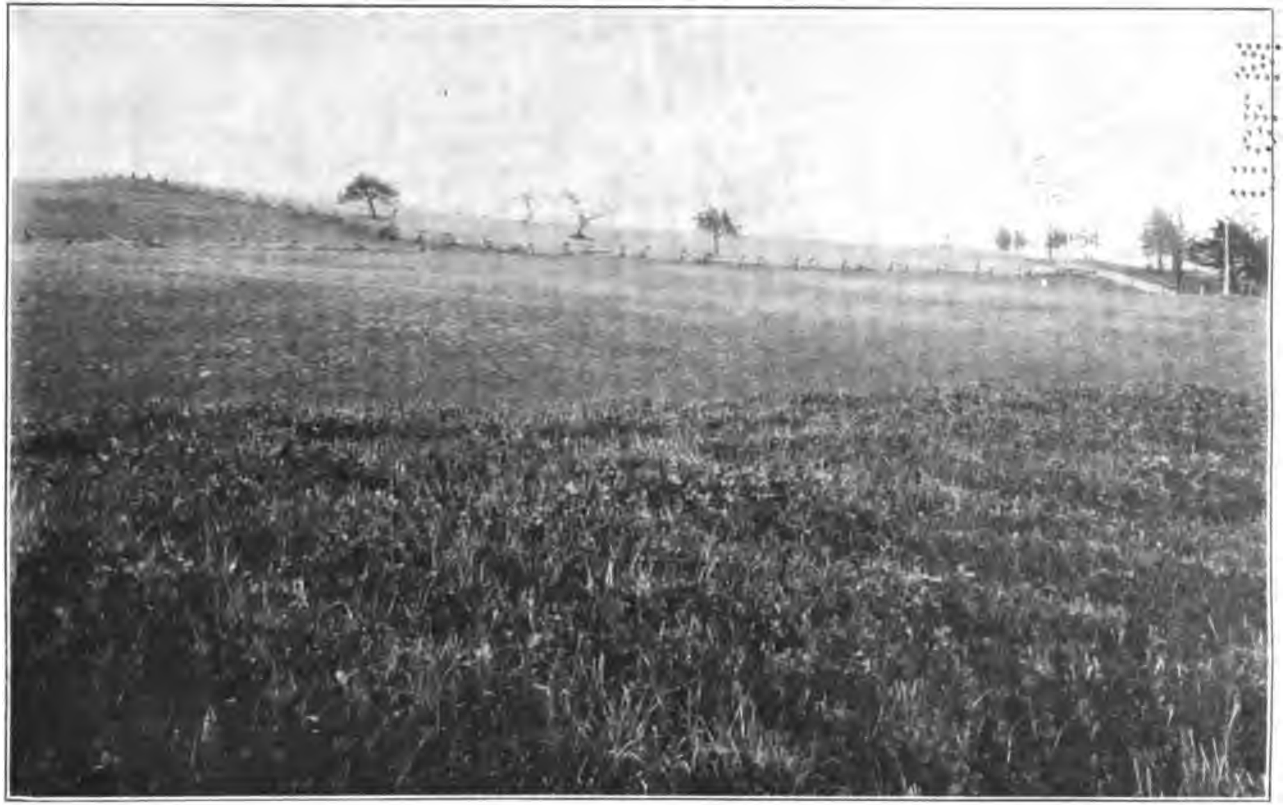
Various reasons have been assigned for the present poor and extensive type of agriculture followed on the Volusia soils where these unfavorable soil conditions have developed. Chief among these reasons is that the soils are "worn out." Distance from markets, poor transportation facilities, isolation of the sections in which the soils occur, poor schools, and unfavorable social conditions have all been suggested as causes of the decline of agriculture in the region. The fact remains, however, that the soils are not exhausted in any reasonable sense of the word. They are not "worn out," but are still capable of producing abundant yields of those crops to which they are adapted, if certain unfavorable soil conditions are remedied and proper tillage and soil management methods are employed. The distance from markets is less than it was when, in the early days, the whole region was still prosperous. The markets are better than ever before. The means and facilities for the transportation of the products of these soils are far better and more efficient than in the pioneer days. The isolation is much less than formerly, and is diminishing by reason of better roads, rural free delivery of mail, rural telephone lines, more and better steam and trolley roads, nearer and larger villages and cities, and the use of horses instead of oxen.

We must concede that these changes for the better have taken place, while at the same time agricultural conditions have been growing worse, though undoubtedly it is a matter of fact that the condition of the schools, of the churches, and of other social institutions has visibly declined with the decline of agriculture in many sections. However, when we analyze clearly the whole situation with reference to these soils we can arrive at no other conclusion than that the fundamental problem is a soil question and that the social and economic problems are only incidental and resultant problems, for they have not developed on some other soils which are just as unfavorably located.

THE USES OF THE VOLUSIA SOILS.

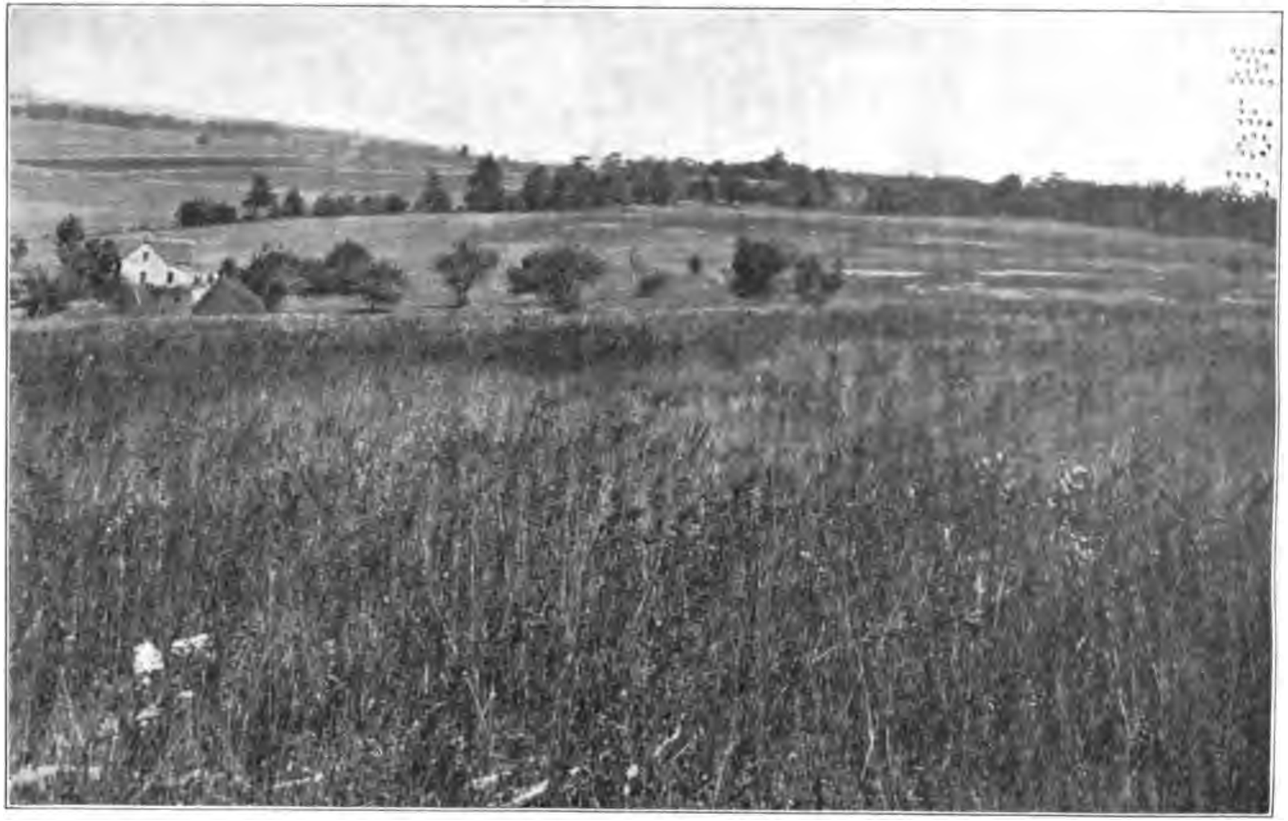
The types of agricultural industry for which the Volusia soils can be profitably used are somewhat varied. However, no line of farming should be introduced which does not include animal husbandry in some form, either as a principal or subordinate feature of the farm practice.

The Volusia silt loam is adapted to the production of late Irish potatoes, oats, buckwheat, and hay. Alsike clover and timothy should be used for grass seeding, except where the soil is in better condition and no difficulty is experienced in growing red clover. Meadows in good sod will yield from 1½ to 2½ tons of hay per acre, though this yield is far above the average for the type as a whole. The timothy is always of excellent quality. However, where the soil is in poor condition there is extreme difficulty in securing a stand of the tame grasses and clovers and difficulty in maintaining the sod also. Of the grasses, redtop does best where these conditions prevail. Permanent sods soon become infested with weeds and wild grasses;



A VOLUSIA SILT LOAM FIELD.

Note the excellent stand of red clover in the foreground and the scant herbage, not enough to cover the ground, in the back part of the field. The whole secret here is, one part of the field was top dressed with stable manure and the other was not.



AN UNOCCUPIED VOLUSIA SILT LOAM FARM.

This plate shows the general lay of the land on the top of the high hills occupied by the Volusia soils. Note the gently rolling surface, favorable to the use of all kinds of farm machinery. Note also the two small haystacks at the left, the total product of this farm for the season of 1907, and the poor herbage in the foreground. These fields were neither mowed nor used for pasturage.

M 70 U

in many places "poverty grass" (*Danthonia spicata*) takes complete possession of the soil. This variety of herbage has but little feeding value either for hay or grazing. In other places on the high hills permanent sods are becoming filled with the devils paint brush or orange hawk weed, completely ruining the sod for either pasture or meadow.

Oats are an excellent crop, though the average yield is not as high as the soil is capable of producing. Yields of improved varieties have in recent years exceeded 50 bushels per acre, though the average is likely not more than 20 to 25 bushels per acre.

Buckwheat is especially suited to this soil type and with reasonably good care yields from 12 to 25 and even 30 bushels per acre. A large acreage is grown, much of which is planted on fields where other crops have failed to make a stand, or where the poor drainage conditions have prevented preparation for earlier crops.

Late Irish potatoes should generally form the main money crop of the rotations on farms of this soil type. The quality of the potatoes grown on this soil is unsurpassed, and the yields are comparatively larger than are those of other crops. The average yield per acre ranges from 100 to 150 bushels, though it is not impossible to secure, and many potato growers are securing, as high as 200 bushels per acre or more with strong seed, judicious fertilization, and improved methods of culture.

Corn for ensilage, an important product in connection with dairy farming, usually does well, but it is not to be considered for the production of grain unless some particularly early variety is planted. Mangelwurzels, carrots, and rutabaga turnips are excellent crops for this soil and can well take the place of some of the grain crops. They furnish excellent feed for dairy cattle and sheep.

Sweet corn, pease, and string beans for canning make excellent money crops where the haul to canning factories is not too long.

Where drainage conditions are favorable and the bed rock is not too close to the surface, well-selected areas are suited to apple orcharding if varieties are selected which are adapted to the soil, but the setting of fruit trees can not be recommended upon the poorer areas, even though other conditions are favorable.

The Volusia loam is a better soil for general farm crops than is the silt loam. It is usually better drained and deeper. This type is adapted to the production of potatoes, hay, oats, corn, buckwheat, and tree fruits. It is also a good soil for dairy farming and stock raising.

In the production of potatoes it is a little more sure than is the silt loam and the yields will likely average a little higher. Sod land usually produces better crops of hay, there being much less difficulty experienced in growing clover and other legumes. The sod remains in good condition longer and the weeds are not able to crowd out the tame grasses so easily. Meadows in good condition will yield 2 to 2½ tons of good quality of hay annually, and when plowed for the intertilled crops give a better seed bed than is usually the case with the silt loam. Oats are excellent both in yield and quality. An average crop will yield from 35 to 50 bushels per acre, with an excellent quality of straw for feeding or bedding. Corn is a much surer crop than when planted on the silt loam, the average yield being from 50 to 75 bushels of ears per acre, with a quantity of dry stover. Buckwheat usually gives a yield about one-third greater than it does on the silt-loam type.

The culture of apples in farm orchards is general on the Volusia loam, and orcharding might well be extended on a commercial scale, provided the location of orchards is made with care and varieties are used which are suited to the particular soil.

Dairy farming and stock raising are industries well suited to this soil and should be developed on a larger scale than they now are.

The Volusia gravelly loam is the lightest, warmest, and earliest type of soil of the series. It is suited to the production of hay, corn, potatoes, etc. It is the best corn soil of the series and seldom fails to produce a good crop. Potatoes also do well. Excellent clover can almost always be grown.

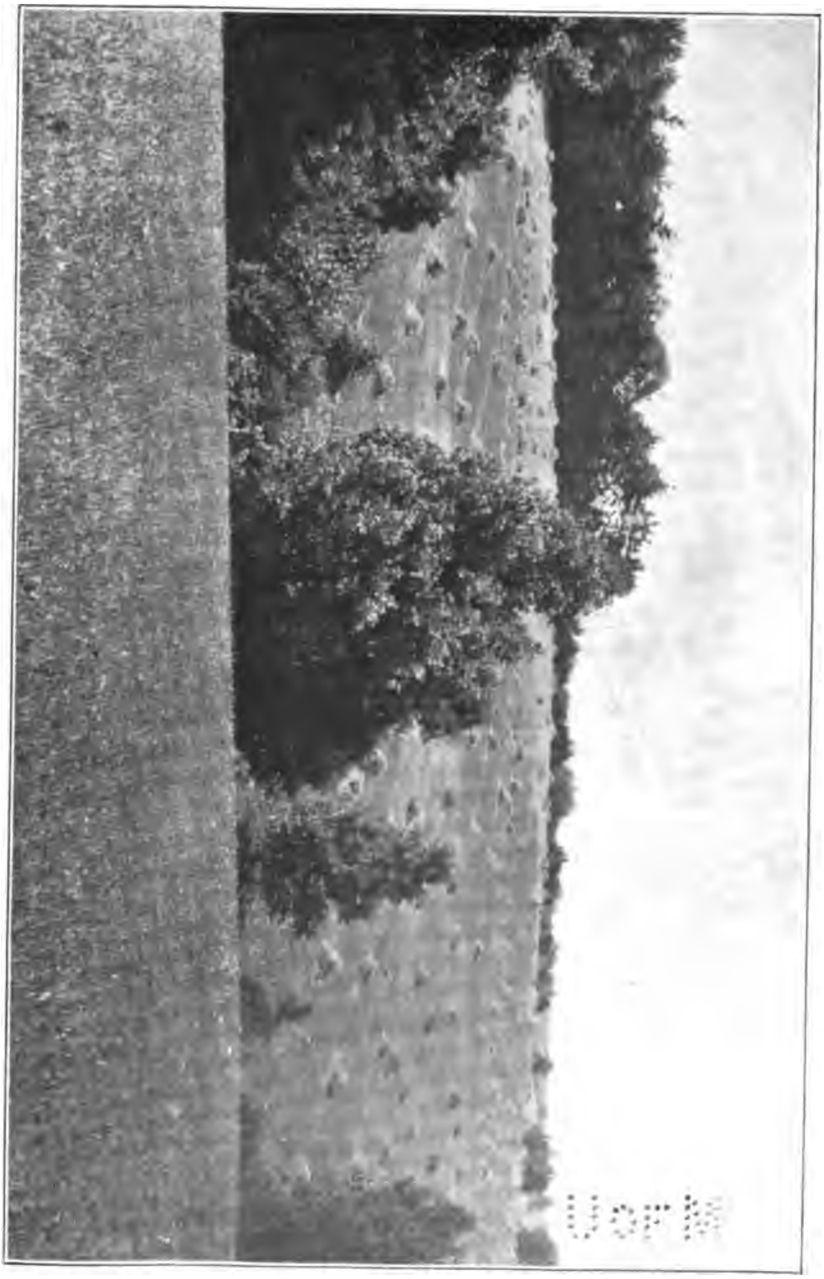
The Volusia clay loam is well adapted to the production of hay, though the clover often " heaves " out.

The Volusia stony loam is a good general farm soil adapted to the growing of such crops as hay, oats, and buckwheat. These crops yield as follows: Hay, 1 to 2 tons; oats, 25 to 40 bushels; buckwheat, 15 to 25 bushels. The tree fruits also do well on this soil type.

Within the whole region occupied by these soils there are certain areas of waste land which should be used for forestry. Many of these areas, from the nature of the surface, are unfit for crops requiring intertillage and are covered with a generally poor growth of timber. This waste land amounts to about 12 per cent of the total area of the region, including both hills and valleys. Many other areas, now included in hillside pastures or abandoned fields, should never have been cleared, but should have been left in forest to furnish a continual income instead of being cleared, cultivated for a time, and then abandoned, producing no income at all. All these areas can be profitably reforested to such valuable timber trees as chestnut, white pine, and hemlock.

IMPROVEMENT OF VOLUSIA SOILS.

Underdrainage is one of the most important steps in the improvement of the Volusia soils and should precede any attempt at building up these soils in other ways. A large percentage of the Volusia silt



A VOLUSIA SILT LOAM HAYFIELD.

Excellent yield of timothy and alsike clover.

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ONE OF THE UNOCCUPIED FARMHOUSES ON THE VOLUSIA SILT LOAM.

This Volusia silt loam property, consisting of 18 acres, is not used for any purpose whatsoever. Directly across the highway are two Volusia silt loam farms of about 150 acres each, which are unoccupied and not producing an income more than sufficient to pay expenses and taxes, while some neighboring farms of the same soil are producing good crops.

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loam type is greatly in need of this improvement. Although this soil type is rolling to hilly in character and surface drainage is well established, subsurface drainage and internal moisture movements are effected only with extreme difficulty. The texture and structure previously discussed combine to prevent to a large extent these necessary moisture movements. And finally, there are many wet areas upon the hillsides, caused by the welling up and out of water from the stratification and joint planes of the underlying bed rock and by seepage from higher levels. Then, too, some portions of the type occupy flat-topped elevations, which are almost always too wet for profitable cultivation unless artificially drained.

But one reason exists to prevent the complete underdrainage of the Volusia silt loam, and that is more apparent than real; that is its low selling value, which is in many cases less than the initial cost of the necessary drainage improvement. However, thorough underdrainage would not only result in increased quantity and better quality of the crops grown, but would greatly enhance the value of the land. It would cause new water courses to be formed within the soil. It would aid in improving the present unfavorable structure of the soil and make possible better aeration and oxidation. All these changes will result in more favorable conditions for bacterial activity and for the development of the favorable humus content of the soil.

The Volusia loam, while not so badly in need of drainage, would respond to such improvement with greater yields and a better quality of crops. The Volusia stony loam and clay loam stand in about the same relation to this improvement as does the loam. The Volusia gravelly loam is of an open structure and loose texture and consequently is well drained naturally.

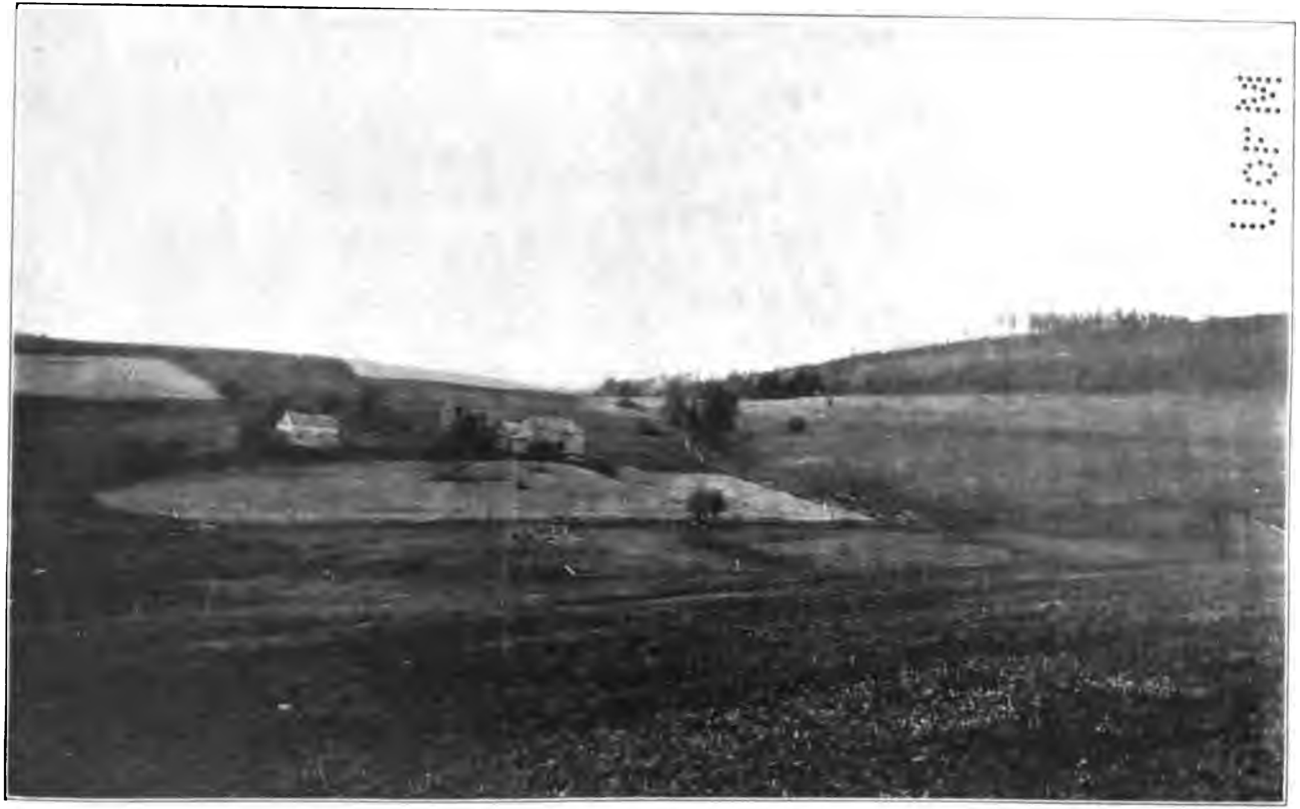
Following drainage, the next step in the improvement of the Volusia soils should be the incorporation of organic matter with the soil. Suggestions in this connection are particularly applicable to the silt loam type, but are also of value to a greater or less degree if applied to the other types of the series.

When these soils were first cleared and produced good crops the humus content was fairly good, but with the systems of soil management and cropping given them and the changes which have taken place in them the organic matter content has been reduced to a minimum. That this has an important effect upon the yield of crops is certain. A larger content of organic matter would not only aid in securing and maintaining a better soil structure but would also enable the soil to retain and deliver throughout the growing season larger quantities of water to the growing crops. It would make the range of moisture content under which tillage could be undertaken wider, as well as lessen the chance of damage from an excess of water in the early part of the season and a shortage during the dry periods in late summer and fall. It would also give rise to more favorable conditions for the activities of soil bacteria.

There are several methods by which this restoration of organic matter to the soil can be accomplished. The most common method is likely the best of all—the liberal application of stable manure. It has been demonstrated by laboratory work that the organic matter content of stable manure is more beneficial in the economy of crop production than is either the mineral content of the manure or any of the inorganic manures. Therefore much more can be accomplished in the improvement of these soils by the use of stable and organic manures than can be brought about by the use of the commercial fertilizers alone. In this connection, no forage crops should be sold from the farms of the Volusia soils; the sale products should always be those which can be marketed in a concentrated high-priced form or in a form containing a large amount of watery matter and a small amount of solid matter. In the past the practice has been largely the reverse of that advocated here, many forage and grain crops having been grown and sold. This practice has succeeded in almost completely exhausting large areas of the Volusia soils of their original stores of organic matter and in many cases almost nothing has been done by the tillers of the soil either to maintain or restore this organic matter, without which no successful crop production can be realized.

As before stated, care should be taken to return in the form of stable manure as much as possible of the crops produced by the soil. This should be augmented wherever and whenever practicable by the practice of green manuring, the growing and turning under of such crops as buckwheat, rye, clover, etc. Wherever possible leguminous crops should be grown, thus increasing the nitrogen in the soil, the most costly of all the ingredients of the commercial fertilizers.

Coincident with efforts to increase the organic content of the Volusia soils should be an effort to correct other unfavorable conditions of the soil. In this connection the use of lime is manifestly of prime importance. Lime alters existing chemical conditions, making the soil more favorable for bacterial life and a better home for the legumes. It will interact chemically with the soil-forming minerals, rendering more readily available some of the materials necessary for plant growth, but at present locked up in chemical combinations which normally withhold the elements needed by the plant. It will also aid in establishing and maintaining a physical condition of the soil more favorable to crop production. It is believed too that the presence of lime has the effect of causing the decaying organic matter to take more permanent forms and to be more beneficial in its effects upon plant growth. As a matter of precaution the application of



ANOTHER FARM WITH THE HOUSE AND BARN GOING TO DECAY.

This farm is rented by a neighbor at a nominal figure. The buildings are going to ruin and the fields producing only low yields. Note the favorable lay of the land for the use of farm machinery.

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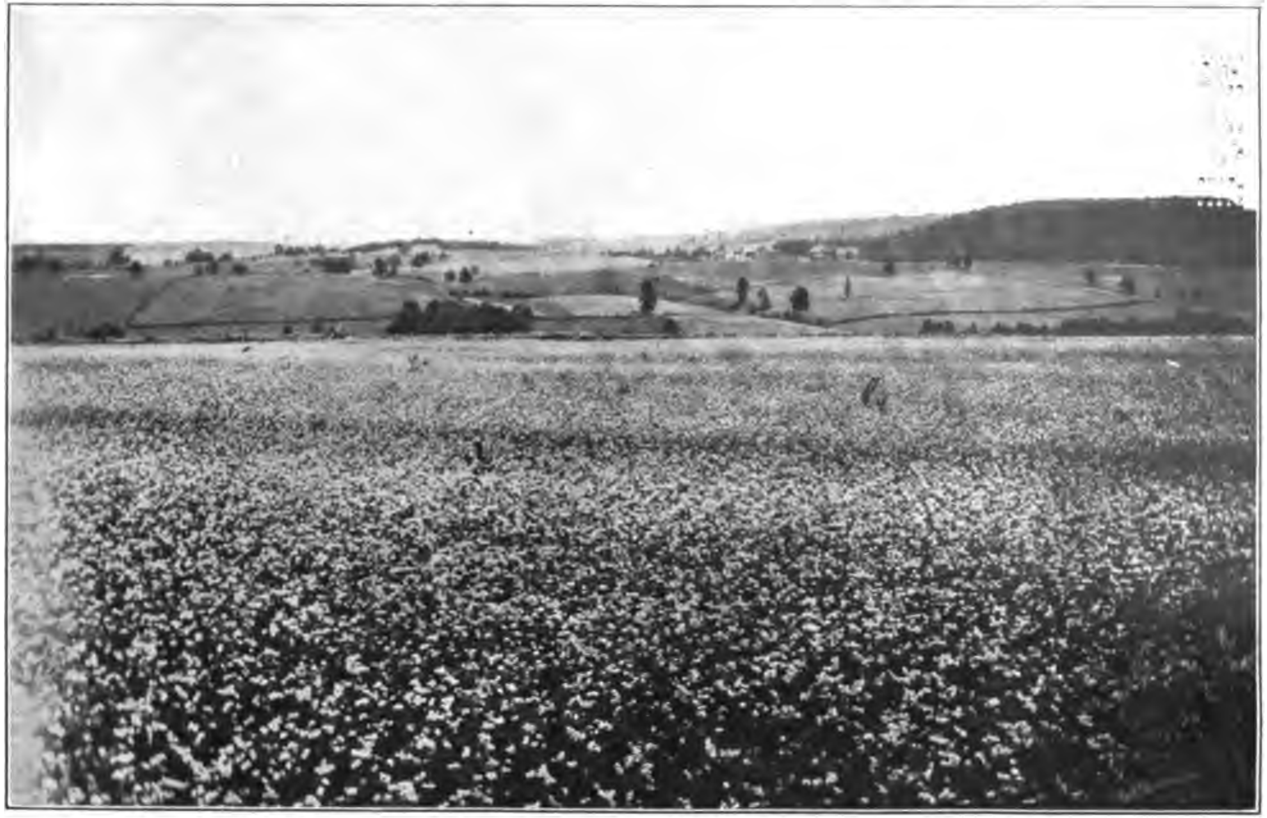
A VOLUSIA SILT LOAM POTATO FIELD.

This man with an annual acreage of 10 acres is securing an average yield per acre of over 200 bushels of late Irish potatoes of unsurpassed quality, while the average yield for the county in which the farm is located is less than 100 bushels per acre, including the production of the valley soils supposed to be more productive.



BUCKWHEAT ON VOLUSIA SILT LOAM.

Note the favorable lay of the fields, the excellent stand of buckwheat. This crop was planted on a field after corn had failed to make a stand, thus preventing loss of the use of the land for the season.

lime to the soil should never immediately precede the use of the soil for potatoes. The best place to use it in the rotation would be with or immediately preceding the seeding for sod.

Another means of improving the Volusia soils, and this applies equally to all types of the series, is deeper plowing, more thorough harrowing, and subsequent better cultivation of all of the intertilled crops. This would result in increasing the crop-producing power of these soils many fold. By more thorough stirring of the soil better aeration is accomplished, more thorough oxidation is brought about, and a better sanitary condition of the soil maintained, which will result in a better home for growing crops. By thoroughly pulverizing the soil the areal surface of the soil grains exposed is made infinitely greater than when the soil is incompletely prepared. In the former case the ability of the soil to store up and deliver moisture to the growing crops is much greater, and the feeding surface for the roots is increased also.

The last suggestion for the improvement and use of the Volusia soils is by no means the least important—that is, the utilization of each type for the production of only those crops to which it is especially adapted. Given these crops, systematic rotations should be worked out for each farm or field. In determining these rotations the fact must be constantly held in mind that the selection is not only limited to such crops as are adapted to the soils, but that the question of the distance to shipping point or market also restricts the choice. Where the farm is remote from a shipping point or market, or where the roads are poor, rough, and hilly, the rotation should include only those crops which can be marketed in a concentrated form easily transported or those which may be fed to stock, which can be driven to market. In other words, the bulky forage crops should not be sold as such but as the finished or manufactured product of smaller volume and higher price. In this way the farmer may make a profit not only on the crop grown directly from the soil, but also on the finished product, and at the same time return to the soil much of the elements necessary for crop production.

SUMMARY.

The soils of the Volusia series are not " worn out " in any proper sense of the word, but so far as the mineral matter of the soil is concerned are abundantly supplied with the plant-food elements for the production of good crops.

The difficulties encountered in crop production upon the Volusia soils arise chiefly from lack of drainage, poor physical condition, and a depletion of organic matter.

The proper management and tillage of these soils require tile drainage over considerable areas of the more clayey soil types, plowing to depths varying with the character of crop to be planted and the existence or nonexistence of hardpan, plowing only when both surface soil and subsoil are sufficiently dry to prevent puddling, the addition of organic matter in the form of stable manure or green crops plowed under, and the application of lime, particularly on the Volusia silt loam prior to seeding down to grass, especially to clover.

The soils of the Volusia series are well suited to dairying, stock raising, and sheep raising, which should be undertaken both for the sake of profit and for the sake of the soil.

Irish potatoes can be advantageously produced on the Volusia silt loam and Volusia loam and constitute the best "money crop" to supplement the animal industry.

The so-called "clover sickness" through the region occupied by the Volusia soils is a soil problem and not a plant problem.

To secure good stands of red clover on the soils of this series thorough drainage, good mechanical preparation of the land, the application of stable manure, and the application of lime at the rate of about 2,000 pounds to the acre are required.

While corn can not be grown for grain production at the highest elevations, silage corn can be produced at all elevations on all types of the series.

Where corn for grain can not be produced to advantage, Canada field peas and oats can be sown as a substitute.

Apple orcharding on a commercial scale is practicable on well-drained areas of the Volusia loam and Volusia stony loam and over a considerable portion of the Volusia silt loam in situations with favorable climatic conditions.

These soils constitute some of the cheapest farm lands now on the market in the United States, and their selling price in the majority of cases is below their actual agricultural value.

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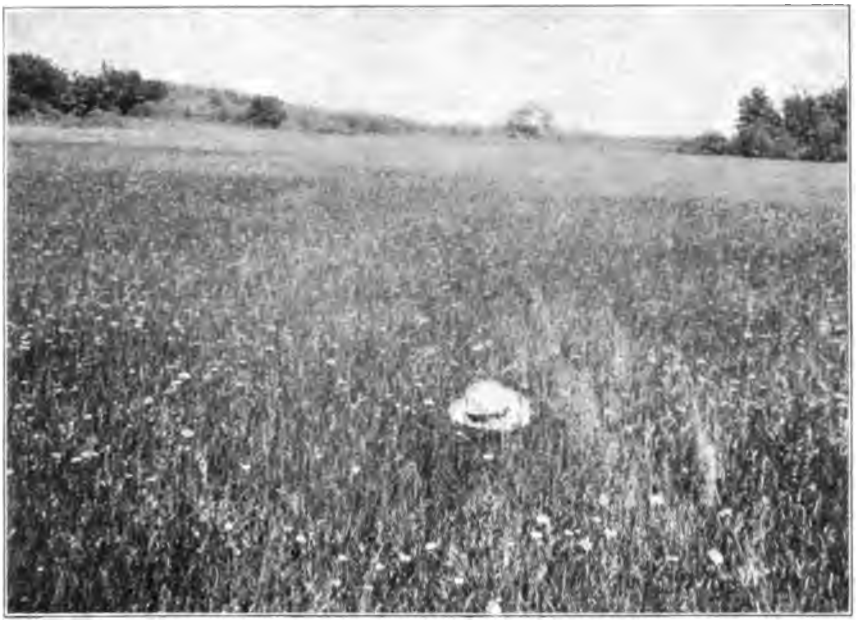

FIG. 1.—A VOLUSIA SILT LOAM FIELD.

The herbage consists of white daisies and poverty grass, *Danthonia spicata*, to the exclusion of other species. This herbage is valueless for either hay or pasture.

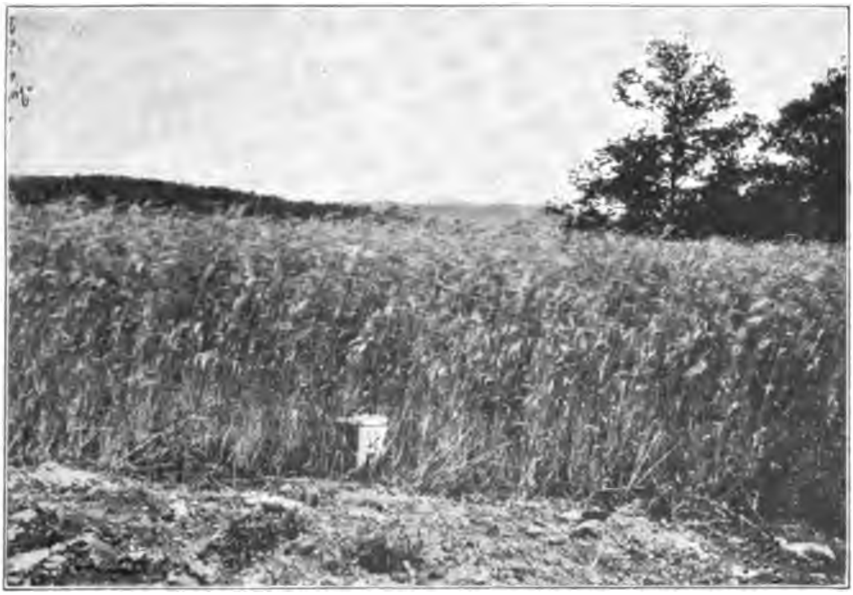

FIG. 2.—AN ADJOINING FIELD SHOWING A GOOD GROWTH OF RYE.

The camera case in the edge of the field is 12 inches in height.

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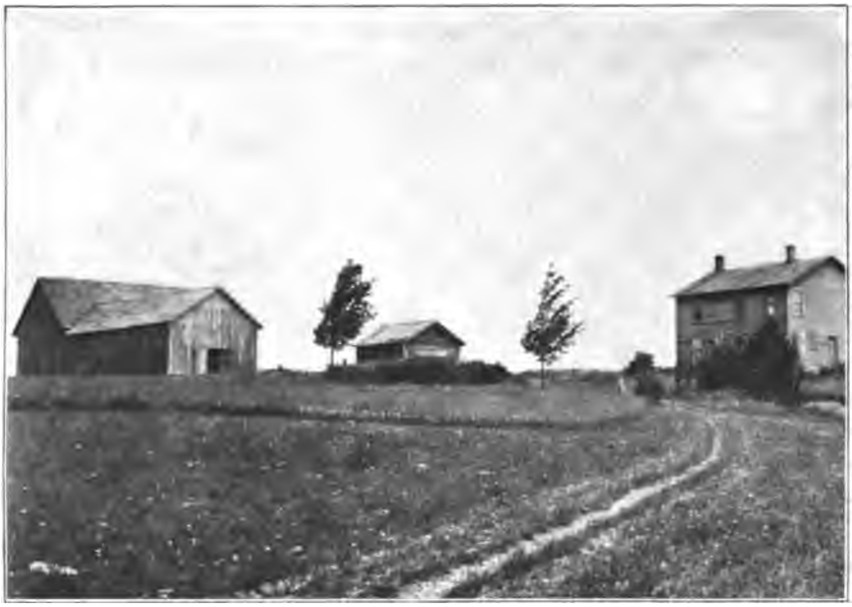

FIG. 1.—ABANDONED FARM BUILDINGS ON VOLUSIA SILT LOAM.

Note that a part of the field has been mowed and a part left standing, the yield and quality of the hay not paying for the harvesting.

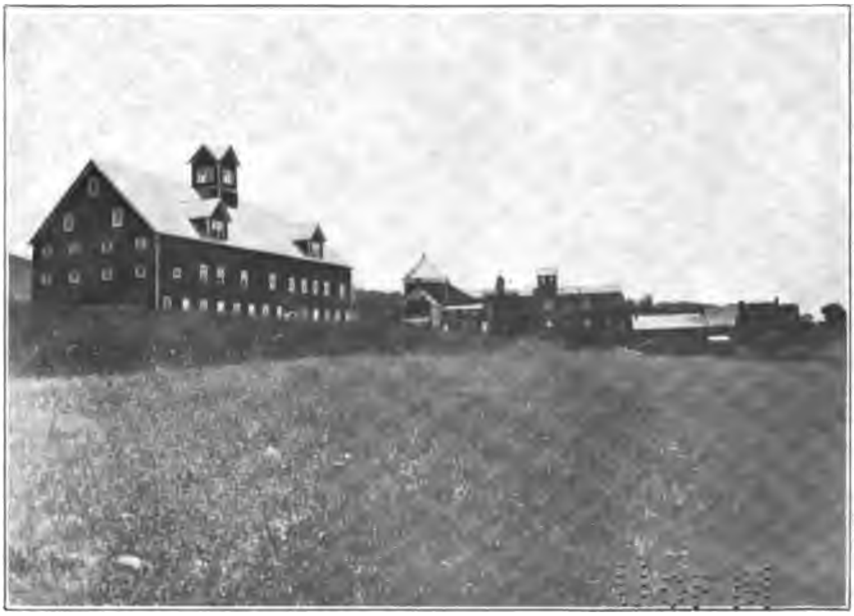

FIG. 2.—BUILDINGS ON A VOLUSIA SILT LOAM FARM IN SIGHT OF THOSE SHOWN IN FIG. 1.

Fields on this farm cut 2½ to 3 tons of timothy hay per acre the same season that the field shown in fig. 1 was left unused and unharvested.

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Issued September 29, 1909.

U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF SOILS—BULLETIN NO. 60.

MILTON WHITNEY, Chief.

A PRELIMINARY REPORT ON THE VOLUSIA SOILS, THEIR PROBLEMS AND MANAGEMENT.

BY

M. EARL CARR.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1909.